REPORT

OF THE

ROTHAMSTED EXPERIMENTAL STATION

FOR

1956

COMMONWEALTH MYCOLOGICAL
4 JUN 1957

Rothamsted Experimental Station
Harpenden, Herts.

LAWES AGRICULTURAL TRUST

REPORT

for

1956

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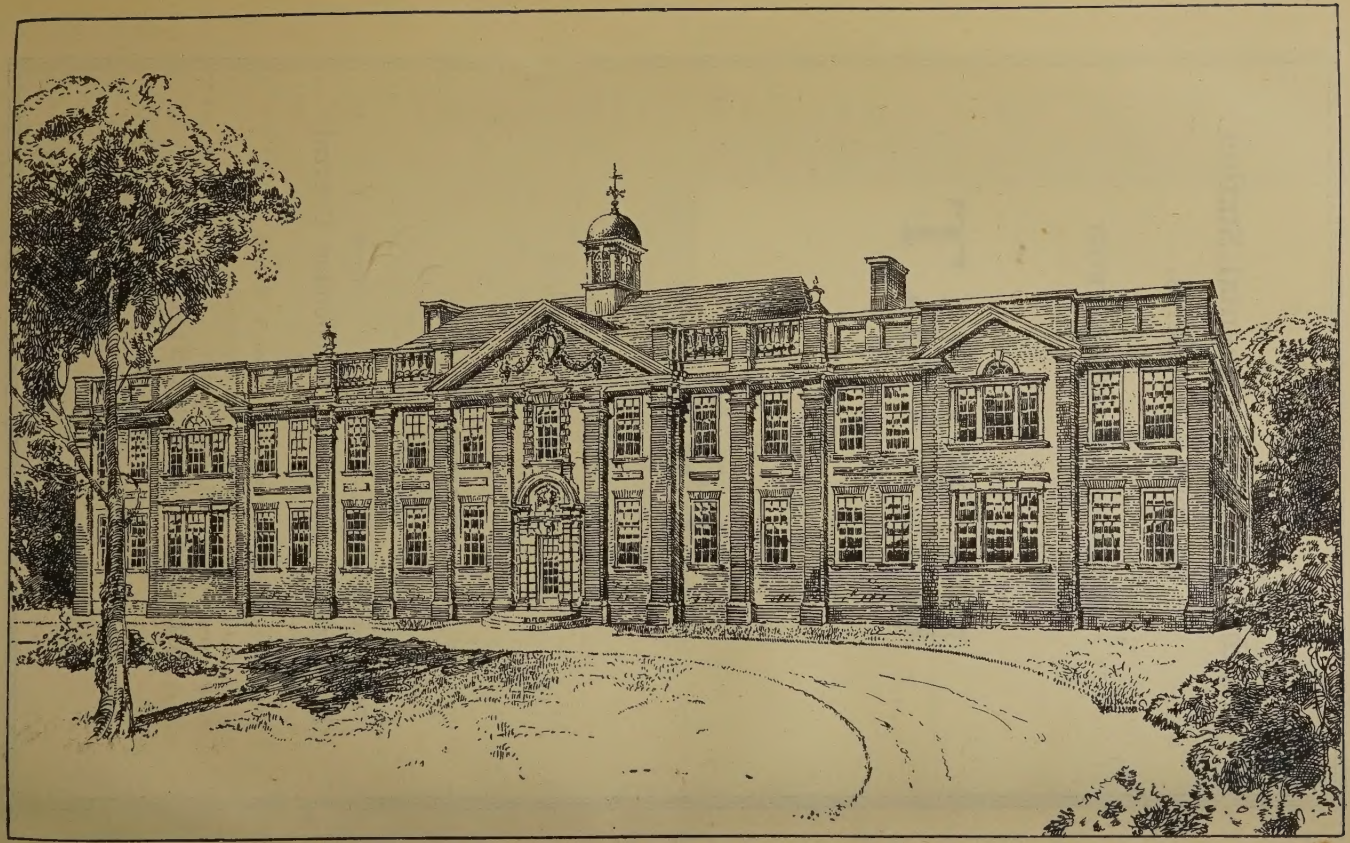

THE ROTHAMSTED LABORATORIES FOR SOIL AND PLANT NUTRITION, ERECTED 1914–1915.

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The following spent varying periods as temporary workers at Rothamsted during 1956 :

Australia : A. H. GIBSON (Soil Microbiology), J. LOVEDAY (Soil Survey), J. W. MEAGHER (Nematology), R. R. STORRIER (Soil Survey); **Belgium :** JEAN SEMAL (Plant Pathology), G. Van Der Ghinst (Plant Pathology); **British West Indies :** CECILY M. THOMAS (Statistics); **Burma :** K. ZAN (Plant Pathology); **Canada :** R. C. ANDERSON (Nematology), E. A. Peterson (Soil Microbiology), J. T. SLYKHUIS (Plant Pathology), J. A. TOOGOOD (Physics), H. E. WELCH (Nematology); **Ceylon :** L. H. FERNANDO (Botany); **Chile :** DORA H. VOLOSKY (Plant Pathology); **Egypt :** M. A. ZAHER (Entomology); **Eire :** J. KILROY (Statistics); **Finland :** P. Kivinen (Chemistry); **France :** J. DEJARDIN (Statistics); **French West Africa :** M. Y. BERLIER (Soil Microbiology); **Germany :** C. K. H. MARTINI (Plant Pathology), J. STEFFENS (Soil Microbiology); **Holland :** W. NIJVELDT (Entomology), J. T. N. VENEKAMP (Statistics); **India :** R. S. BADAMI (Plant Pathology), M. DAS (Insecticides), B. K. GHOSH (Statistics); **Japan :** T. HARADA (Chemistry); **Kenya :** G. L. COULSON (Statistics); **Malaya :** R. SRIPATHI RAO (Nematology); **Nepal :** JEANNETTE TODD (Entomology); **New Zealand :** R. A. HARRISON (Insecticides), P. B. LYNCH (Field Experiments), P. F. NOBLE (Physics), JOYCE WATSON (Botany); **Norway :** L. OVERREIN (Chemistry), O. REIERSØL (Statistics); **Pakistan :** M. A. CHAUDRI (Statistics), A. HANIF (Statistics), D. H. KHAN (Pedology), M. R. TALUKDER (Statistics); **Philippines :** P. SUBIDO

(Field Experiments); **Portugal :** J. C. DA SILVA DIAS (Entomology); **South Africa :** R. L. DAVIDSON (Physics), D. L. MILNE (Entomology); **Sudan :** M. A. NOUR (Insecticides); **Switzerland :** R. A. CHRIST (Chemistry); **Turkey :** HÜSNÜ ISMEN (Plant Pathology); **Uganda :** C. LOGAN (Nematology); **United States of America :** J. G. BALD (Plant Pathology), M. CHESSIN (Plant Pathology), S. W. MELSTED (Chemistry); **West Africa :** R. K. CUNNINGHAM (Chemistry), J. N. EFITE (Chemistry), J. K. OBI (Statistics), F. R. PEERS (Statistics); **British Isles :** F. H. ALSTON (Entomology), K. B. ARMSTRONG (Insecticides), MARGARET K. ARNOLD (Bee), RUTH BABBS (Entomology), W. A. BACKLEY (Insecticides), C. BISHOP (Chemistry), JANET CORNER (Biochemistry), JUDITH COX (Plant Pathology), P. W. W. DABORN (Chemistry), M. DAGG (Physics), NANCY DENHAM (Bee), C. O. R. EVERARD (Nematology), JOAN EVETTS (Nematology), A. J. GIBBS (Plant Pathology), SALLY GREENE (Biochemistry), Z. HAMZAH (Plant Pathology), J. G. HARTLEY (Entomology), ELIZABETH H. HAYTON (Statistics and Insecticides), D. W. R. HEADFORD (Botany), CECILY N. HEBERT (Statistics), A. H. HYDE (Botany), H. JARRETT (Field Experiments), J. W. O. JEFFERY (Pedology), D. I. JENKINS (Biochemistry), JENNIFER M. JONES (Entomology), G. KALMUS (Plant Pathology), ELIZABETH MALLINSON (Plant Pathology), M. G. MANN (Entomology), MARGARET L. MELVILLE (Insecticides), J. W. MILLBANK (Soil Microbiology), PATRICIA M. NELSON (Bee), C. D. OLLIER (Soil Survey), D. A. PERRY (Plant Pathology), A. PINKERTON (Chemistry and Statistics), A. A. RUTHERFORD (Statistics), R. W. SHARP (Statistics), J. STARK (Soil Survey), R. L. STOLZ (Entomology), ANN TERRY (Insecticides), R. WEBSTER (Chemistry), J. WHITAKER (Plant Pathology), A. G. WHITEHEAD (Nematology), T. C. WIGNALL (Statistics).

Soil Survey of England and Wales

Head of Survey

A. Muir, Ph.D.(Edin.)

Deputy Head of Survey

D. A. Osmond, M.Sc., Ph.D.(Bristol), A.R.I.C.

Soil Surveyors

G. D. Ashley, B.Sc.(Sheffield)
B. W. Avery, B.Sc.(Reading)
D. F. Ball, B.A.(Cantab.)
E. M. Bridges, B.Sc.(Sheffield)
C. P. Burnham, B.A.(Cantab.)
B. Clayden, B.Sc.(Sheffield)
C. B. Crampton, B.Sc.(Bristol)
A. Crompton, B.Sc.(Leeds)
D. C. Findlay, B.A.(Cantab.)
R. D. Green, M.Sc.(Lond.)
B. R. Hall, B.Sc.(Edin.)
C. A. H. Hodge, B.Sc.(Wales)
J. H. James, Ph.D.(Bristol)
R. A. Jarvis, B.Sc.(Dunelm.)
D. W. King, B.Sc.(Lond.), A.R.I.C.
D. Mackney, B.Sc.(Bristol)
C. C. Rudeforth, B.Sc.(Lond.)
R. S. Seale, M.A.(Cantab.)
A. J. Thomasson, B.A.(Bristol)
J. P. Watson, M.A., B.Sc.(Oxon.)

Colonial Pool of Soil Surveyors

A. O. Ballantyne, Ph.D.(Edin.) (In Northern Rhodesia)
G. F. M. Murdoch, M.A.(Edin.) (In Swaziland)
J. Stark, B.Sc.(Glas.) (In British Guiana)

Chemists

C. L. Bascomb, B.Sc.(Agric.)(Reading)
Audrey M. Du Feu, B.Sc.(Lond.)
H. H. Le Riche, B.Sc.(Lond.)

Temporary Workers

J. Loveday, M.Agric.Sci.(Adelaide)
R. R. Storrier, B.Sc.(Agric.)(Sydney)

Cartographer

D. V. Jones

Assistant Staff

Pamela Ash, D. Coope, Mrs. Audrey M. Denton-Hughes, Mrs. Joan K. Foster, R. Howell, Sheila Pettitt, Mary R. White, Mrs. Sheila M. Wright

Woburn Experimental Station

Director

Sir William G. Ogg, M.A., B.Sc., LL.D.(Aberd.), Ph.D. (Cantab.)

Assistant Director

H. H. Mann, D.Sc., F.R.I.C. (Kaisar-i-Hind Gold Medal)

Chemist

T. W. Barnes, M.Sc.(Lond.), F.R.I.C.

Assistants

A. Peacock, G. Pearce

FARM STAFF

Head of Farms

J. R. Moffatt, B.Sc.(Agric.)(Lond.), N.D.A., A.I.B.A.E.

Assistant

G. F. Cole

Bailiff

A. W. Neill

Farm Workers

C. Hathaway, R. Holliman, W. Hummerston, K. Parsonage, K. Wilson, W. Wilson

Imperial College of Science and Technology

(Research Institute of Plant Physiology)

Director

F. G. Gregory, D.Sc.(Lond.), F.R.S.

Head of Department

F. J. Richards, D.Sc.(Birm.), F.R.S.

Scientific Staff

E. H. Grice-Hutchinson, B.Sc.(St. And.)
W. W. Schwabe, Ph.D.(Lond.)

Temporary Workers

U. Pethiyagoda, B.Sc.(Ceylon)

Assistant Staff

W. S. Biggs, Priscilla M. Dutton, C. Sinclair, Pamela Smith

The Commonwealth Bureau of Soils

Director	G. V. Jacks, M.A.
Consultant Director ...	Sir W. G. Ogg, M.A., Ph.D., LL.D.
Assistant Director ...	W. D. Brind, B.Sc.(Agric.)
Assistants	G. A. Greenwood, B.Sc. Mrs. M. Kathleen Milne, B.Sc. T. Z. Nowakowski, Ph.D. I. Szladits, Ph.D. Norah J. Watts, M.A.
Indexer	Mrs. Sophie Adams
Clerks	Christine E. Dollimore, Mrs. Iris Lindsay, Marguerita D. Payne, Mrs. Rita M. Starkins

The Bureau is one of ten Commonwealth Agricultural Bureaux, and was established at Rothamsted in 1929. Administratively and financially the Bureau is distinct from the Station, but the closest collaboration exists in the work of the two. The Director of the Station is Consultant Director of the Soil Bureau.

The function of the Bureau is to assist workers in soil science throughout the Commonwealth by providing technical information, by promoting contact between them and by rendering any technical assistance possible when they are in this country. A bi-monthly abstract journal *Soils and Fertilizers*, covering the literature of soil science, fertilizers and the culture of field crops throughout the world, is published, together with occasional monographs—*Technical Communications*—on subjects of general interest. To facilitate its work, the Bureau seeks to be well informed as to the personnel engaged in soil work in the Commonwealth and the problems on which they are engaged. Each Government nominates one of its staff as Official Correspondent to the Bureau, who acts as liaison officer in Bureau matters and assists in the collection and distribution of information. The issue of technical information is usually free to all workers in soil science who ask the assistance of the Bureau.

PREFACE

The Rothamsted Experimental Station was founded in 1843 by the late Sir J. B. Lawes, with whom was associated Sir J. H. Gilbert for a period of nearly sixty years. Lawes died in 1900, and Gilbert in 1901; they were succeeded by Sir A. D. Hall from 1902 to 1912, and by Sir E. J. Russell from 1912 to 1943, when the present Director, Sir William G. Ogg, was appointed.

For many years the work was maintained entirely at the expense of Sir J. B. Lawes, at first by direct payment, and from 1889 onwards out of the income derived from the endowment fund of £100,000 given by him to the Lawes Agricultural Trust. In 1904 the Society for Extending the Rothamsted Experiments was instituted for the purpose of providing funds for expansion. In 1906 Mr. J. F. Mason built the Bacteriological Laboratory; in 1907 the Goldsmiths' Company generously provided a further endowment of £10,000, the income from which—since augmented by the Company—is devoted to the investigation of the soil. In 1911 the Development Commissioners made their first grant to the Station. Since then, Government grants have been made annually, and at the present time over 90 per cent of the necessary funds is provided from Government sources—mainly by the Ministry of Agriculture and the Agricultural Research Council.

The main block of laboratories was opened in 1919; another block was erected in 1924 for plant pathology by a grant provided by the Ministry of Agriculture out of the Development Fund; and Red Gables, the house adjoining the laboratories on the north side, was converted into an Administration Building to hold the Commonwealth Soil Bureau, Staff Common Room and Conference Room.

Since 1945 Rivers Lodge, a house belonging to the Station, on the south side of the laboratories, has been used to provide accommodation for the Statistical Department. In 1946 Rothamsted Lodge, the dower house of the Estate, was purchased and occupied by the Entomology and Bee Research Department.

In 1947 the plant nematology work under Dr. T. Goodey, of the Institute of Parasitology, was transferred to Rothamsted, and a new laboratory was erected to house this department.

Large glasshouses, including special insect-proof houses for virus studies, were added in 1926, 1928 and 1931 by aid of generous grants from the Rockefeller Foundation, the Empire Marketing Board and the Ministry of Agriculture. A new large range of houses, some of which are insect-proof, was erected in 1935 for plant-pathology investigations.

In 1940 the south wing was completed and the old chemical laboratories reconstructed. These extensions and reconstructions provide accommodation for the Chemistry, Biochemistry, Physics and Microbiology Departments; in addition, a range of pot-culture houses was built. In 1939 a laboratory was completed for workers

from the Imperial College of Science and Technology. A West Building, to house the Entomology and Insecticides Departments together with the mycologists of the Plant Pathology Department, was completed in 1955.

The Rothamsted Home Farm of 250 acres came under the management of Sir John Lawes in 1834, the experimental fields being worked from the farm buildings at the Manor House. In 1913 the first range of farm buildings and cottages was erected on the site of the present buildings. These were considerably enlarged in 1930–32 and equipped for electric light and power; further additions were made in 1939–40. A range of six farm cottages was erected in Ninnings Field in 1948, and a concrete road constructed from the back of the laboratories to the farm.

The non-experimental part of the farm was reorganized in 1928 to meet the prevailing economic conditions, much of the land being laid down to permanent grass, and cattle and sheep were introduced. In 1939 this policy was reversed, ley farming was introduced and the arable acreage was increased to meet wartime conditions.

The extension of the experiments to various outside centres in Great Britain, begun in 1921, has proved so advantageous that it has been developed. Not only is useful information spread among farmers, but Rothamsted also gains considerably by this closer association with the universities and Advisory Services. As part of this extension, the Station took over in 1926 the Woburn Experimental Farm. We were thus able to make experiments simultaneously on the light land at Woburn and the heavy land at Rothamsted.

In May 1934 the negotiations for the purchase of the farm and some adjoining parts of the Rothamsted estate were completed. The Lawes Agricultural Trust now owns the site of the laboratories, the experimental and ordinary farm fields, Knott Wood, the Manor House and grounds, the farm manager's house and eight cottages. The total area is 527 acres. The purchase price was £35,000, all of which was raised by public subscription. Generous contributions were received from Sir Robert McDougall and others, and a highly encouraging feature of the appeal was the number of subscriptions received from farmers, village school teachers and from oversea sources.

In 1955 the two fields Delafield and Whittlocks, adjoining the western boundary of the estate and amounting to 26 acres, were bought by the Lawes Agricultural Trust; in 1956 Baldwin's Paddock and Lodge, comprising about 6 acres near Hatching Green, were also bought, together with Geescroft Wilderness (3 acres) and Road Piece (a strip of about 16 acres running along Redbourn Lane).

During 1951–52 the Manor House was converted into a Hall of Residence, providing accommodation for seven families, rooms for twenty single workers and two guest rooms. Some of the large public rooms are available for lectures and general institutional purposes. The fabric of the older part of the building, part of which dates back to the 13th century, has been carefully preserved. The greater part of the cost was met by the Ministry of Agriculture, but the Station also received encouragement and financial aid from the

Pilgrim Trust. The conversion has greatly enhanced the amenities of Rothamsted, and the accommodation is particularly useful for the younger members of staff and temporary workers from overseas. An illustrated guide to the Manor with an account of its history has been published (1953) under the title *The Manor of Rothamsted*.

The activities of Rothamsted, however, are not confined to the British Isles, but are gradually reaching out to many parts of the world. The Station regularly participates in work for the solution of agricultural problems of great importance to the Commonwealth.

Rothamsted offers research facilities for post-graduate students, but unfortunately the number of additional workers that can be accommodated is at present strictly limited by lack of laboratory space.

The Commonwealth Bureau of Soil Science, one of the ten Commonwealth Agricultural Bureaux set up to act as clearing centres of information on agricultural science, has been located at Rothamsted since its establishment in 1929.

The Library

The Library may be said to have come into being in 1913, when the Sir Henry Gilbert Collection, presented by Lady Gilbert, was added to the small body of reference works used in the Laboratory at that time—most of them the gift of Sir John Lawes himself.

Its expansion, aided by gifts and grants from a number of individuals and societies, was rapid, until it now contains :

	(Approximately)
Periodicals ... ... (Current, about 1,600)	4,800
Books, 1841–	11,000
Books, 1471–1840 ... ... (including 14 incunabula)	3,500
Bound volumes of pamphlets	400
MSS.	100
Maps	300
Prints (excluding those in books and journals) ...	300

—in all about 18,000 items, comprising some 53,000 volumes.

The yearly accessions of books and periodicals, bought and exchanged, amount to approximately 1,100 volumes.

The chief periodicals on agriculture and related subjects published throughout the world are received, either by subscription or in exchange, and constitute the most-used section of the Library.

The stock of books also covers a wide range of subjects—not only agriculture but also, e.g., chemistry, physics, biology, botany, geology, zoology, meteorology and statistics. The books are arranged according to the Universal Decimal Classification system. The collection of early printed books (1471–1840), which is kept separate from the rest, includes fourteen incunabula, amongst which is a copy of the first dated edition of Pier de' Crescenzi's *Ruralium commodorum libri duodecim*—the earliest printed book on agriculture

—produced at Augsburg by Johann Schüssler in 1471 (Hain 5828). The collection of MSS. includes a copy of the *Treatise of Husbandry*, by Walter of Henley (fl. 1250), written in England on vellum about the middle of the 14th century.

The prints, which are mainly of the 18th and early 19th centuries, include portraits of eminent agriculturists, bucolic scenes, and representations of livestock. A most valuable addition to this collection was made in 1948, when Lord Northbrook presented to Rothamsted his father's collection of prints.

The Library is designed to meet the requirements of the staff of Rothamsted; but its use may be extended to any research worker who can show his need of it.

The General Catalogue of the Library is kept on cards. There is also a published catalogue of the collection of early printed books on agriculture (Rothamsted, 1926; second edition, 1940; supplement, 1949). A complete catalogue of the serial publications in the Library was published in 1954.

The *Quarterly bulletin of the International Association of Agricultural Librarians and Documentalists* is edited and published in the Library.

INTRODUCTION

By the Director

We record with regret the death of a granddaughter of Sir John Bennet Lawes, Mrs. Donald MacAlister, née Everilda Creyke, who took a keen interest in the work of Rothamsted; also the death of Mr. F. K. Hawkins, a member of the staff for thirty-one years.

Dr. H. H. Mann, who has been deputy director at Woburn since 1928, retired at the end of the year and Mr. C. A. Thorold, until recently Principal Research Officer at Moor Plantation, Ibadan, Nigeria, succeeds him in January 1957, as Officer in Charge. Dr. F. Tattersfield, who has continued his research work in the Insecticides Department since retiring from the headship in 1947, retired in September, and Mr. B. Weston, Field Superintendent, retired in December after forty-six years' service. All three have given outstanding service to the Station. Dr. G. W. Cooke was appointed head of the Chemistry Department in March in place of Dr. R. K. Schofield, who has been appointed Reader in Soil Science at Oxford University.

Mr. M. J. R. Healy was awarded a Rockefeller grant to visit research institutes in the U.S.A. and Canada. Dr. I. Stephen accepted a temporary part-time appointment at the University of Illinois, and Miss S. G. Heintze has leave of absence for a year to work at Rukuhia Soil Research Station, Hamilton, New Zealand. Dr. P. W. Arnold and Dr. C. G. Johnson have been seconded to the West African Cocoa Research Institute, Tafo, Ghana, and Mr. B. M. Church to the Food and Agriculture Organization of the United Nations to work in Ethiopia, mainly on the setting up of agricultural surveys. Dr. D. W. Fenwick spent three months in Trinidad investigating Red Ring disease of coconuts, and Dr. F. T. Last has been seconded to the Research Department of the Sudan Department of Agriculture to study blackarm disease of cotton. Dr. D. A. Osmond visited Malta in connection with a soil survey of the island, and Mr. R. S. Seale and Mr. A. J. Thomasson have been seconded to Hunting Aerosurveys for six months for soil-survey work in Iraq.

Sir William Ogg visited potash mines in France and Germany and some of the centres at which research on potash fertilizers is being carried out. Dr. H. G. Thornton visited the U.S.S.R. with a delegation from the Royal Society, and Dr. F. Yates spent two months in India on a Technical Assistance Mission of the United Nations. Dr. H. Greene paid visits to British Guiana, Trinidad, British Honduras and Jamaica, and later in the year he went to Australia to attend the Symposium on Arid Zone Climatology organized by UNESCO, visiting North Borneo, Sarawak and Aden on his return journey. Mr. D. H. Boalch attended a meeting in Munich of the Executive Committee of the International Association of Agricultural Librarians, and Mr. F. G. W. Jones a meeting at Münster to discuss the formation of a European Nematology Society. Dr. Mary Glynne accepted invitations from the Departments of

Agriculture for Eire and Northern Ireland to survey cereal crops for eyespot disease, and Mr. F. C. Bawden lectured at University College, Dublin.

Dr. H. F. Barnes, Dr. Marion Watson and Mr. M. J. Way attended the 10th International Entomological Congress in Montreal, and Dr. J. L. Monteith accepted an invitation from UNESCO to a Conference on Agricultural Meteorology in Australia. Mr. N. W. Pirie took part in a Conference on Chromosomes at Wageningen and a Symposium on Modern Ideas on Spontaneous Generation arranged by the New York Academy of Sciences. Several members of the staff attended meetings of the International Institute for Sugar Beet Research in the Netherlands, Belgium and France, and there was a large delegation from Rothamsted to the 6th International Congress of Soil Science in Paris.

Visitors

Visitors from abroad included Dr. Sonnemann, Staatsekretar, West German Ministry of Agriculture, Forestry and Food; Mr. Jamil Mualla, Director of Agriculture, Syria; H.E. Sayed Mirghani Hamza, Sudan Minister of Agriculture, Irrigation and Hydro-Electric Power, and Mr. Wadie Habashi, Director of Agriculture in the Sudan; Mr. Derwish El Haidari, Director General, Agricultural Division, Iraq Development Board; Dr. M. M. Hafez, Controller General of National Research Council, Egypt; Chief Akin Deko, Minister of Agriculture and Natural Resources, Western Region of Nigeria; Mr. Milan D. Smith, Executive Assistant to the Secretary for Agriculture of the U.S.A.; Dr. J. G. Harrar, Director for Agriculture of the Rockefeller Foundation; Professor G. Torstensson of the University of Uppsala and Professor O. Pohjakallio of the University of Helsinki. Amongst visitors from the U.S.S.R. were members of an agricultural delegation invited by Her Majesty's Government; Professor I. V. Tiurin, Director of the Dokuchaev Soil Institute, Moscow; Dr. A. V. Sokolov of the same institute; Professor V. A. Kovda of Moscow University and the Soil Science Institute of the Academy of Sciences; Professor Sukhorukov of the Botanic Gardens, Moscow, and Professor V. E. Shubin of Stalingrad University. Many parties visited the Station, including the International Union of Forest Research Organizations, the Biochemical Society and delegates to the 4th Congress of the International Potash Institute.

Buildings and Land

The work of certain departments has been seriously handicapped by unexpected delays in provision of additional glasshouses and laboratories.

Baldwin's Paddock and Lodge, comprising 6 acres near Hatching Green, were purchased during the year, together with 3 acres of woodland and 16 acres of agricultural land adjoining Redbourn Lane.

The Work of the Station

The work on soil structure and soil conditioners has been continued in the **Physics** Department, and a laboratory permeability

test which gives a quantitative measure of soil structure has been improved and simplified. In a field experiment the effect of a ley in improving structure has been shown in better germination of beet and increased yields of carrots. Further studies have been made of the surface physics of clays, particularly on quantitative measurement of electric charges on kaolin crystals.

On the meteorological side, the recording of the environment (microclimate) in potatoes and wheat is proving valuable in the study of diseases and pests of these crops. Data on condensation and evaporation of moisture are particularly useful, and a special anemometer has been designed and built to give a continuous record of low wind speeds within the foliage of the crops. In the irrigation experiment at Woburn, water applied during the early summer drought gave increases in yield in the first two cuts of grass; on the barley there was a marked response in the early stages of growth, but wet weather followed, and there was only a moderate increase in yield of grain.

The current programme in the **Chemistry** Department on fertilizer placement is now being concluded. The experiments over the last few years on potatoes have demonstrated considerable benefits from placement of both ammonium sulphate and potassium sulphate close to the seed when the crop was planted from the flat by machine. The gains were greater with light than with heavy dressings, emphasizing that if the amounts of fertilizers are restricted for any reason, care should be taken to apply them properly. On barley, muriate of potash combine-drilled consistently gave higher yields than twice the quantity broadcast. In a three-year series of experiments on spring-sown cereals, combine-drilling ammonium sulphate gave at most centres larger yields than broadcasting, the average gain being nearly 2 cwt. grain/acre. Other experiments indicate that the top-dressing of spring barley with nitrogen in May should not generally be recommended, as in wet years it may cause serious lodging, uneven quality of grain and poorer yields. These investigations, however, have been confined to a limited area of the Eastern Counties, and should be repeated over a wider range of soil and climatic conditions.

Different nitrogen fertilizers are being compared on a variety of crops. Preliminary results indicate little difference between ammonium sulphate and calcium nitrate for spring-sown cereals, and the same is true for kale and potatoes at light dressings, but at heavy rates ammonium sulphate was the better fertilizer for potatoes. An imported granular urea containing 43 per cent nitrogen seriously damaged both potatoes and kale, possibly due to the presence of biuret. This emphasizes the importance of testing new materials thoroughly in the field before they are put on the market. Losses of nitrate nitrogen by denitrification have been investigated, but these are not likely to be serious if the water content of the soil is less than 60–70 per cent of the water-holding capacity. An account of the accumulation of organic matter and fertilizer residues in the soils of the long-term experiments has been prepared, and progress has been made with the laboratory work on the nature of soil organic matter. In the investigations on the nutrition of forest-tree seedlings at Wareham, copper-deficiency diseases have been

diagnosed on poplar and Sitka spruce seedlings, and both can be cured by copper sprays.

One of the main lines of work in the **Pedology** Department concerns the parent materials from which soils are derived, and a detailed investigation is being made of the weathering of igneous rocks in Shropshire and of the soil types found in these rocks. The study of the clay minerals of sediments has been extended to a wide range of clays and limestones, and in the Chiltern area evidence from sand mineralogy shows the complex nature of the drifts overlying the chalk. Microscopic examination of thin sections of soils has thrown light on the morphology of soils and on problems of soil classification. Various investigations are in progress on the physical chemistry of soil minerals. Calorimetric methods are giving important information on the formation of soil aggregates and on the location of exchangeable bases. Work is also continuing on iron oxides, on water absorption by clay minerals and on the fixation of potassium by soils. On the spectrochemical side, further work has been done on the trace elements in Lower Lias shales, the parent materials of some soils in Somerset on which the cattle disease known as " teart " occurs. Samples from South Wales are also being investigated. Progress has also been made in the study of the effect of water extracts of various leaves on the constituents of soil profiles.

A considerable part of the work of the **Soil Microbiology** Department deals with biological interactions in the soil that encourage or control the growth of micro-organisms. These micro-organisms, and particularly the population in the immediate neighbourhood of the roots, can influence the supply of plant nutrients and may also include disease organisms. A group of bacteria resistant to certain antibiotics (streptomycin and chloromycetin) has been found to be abundant in the root surroundings but rare in soil away from the roots. A study is also being made of a factor or factors in fresh soil that inhibit the germination of the spores of certain fungi. This inhibitory action is destroyed by heating soil, and is also prevented or reduced by the presence around the fungal spores of certain sugars and in some cases by plant roots. Progress has been made with the investigation on the decomposition of herbicides and insecticides in soil, and a detailed investigation begun on the process of root-hair infection by the nodule organism. There are great differences in the number of infected root hairs on different clover species. This work should throw light on the roles of host plant and bacteria in controlling the numbers of nodules.

Investigations in the **Botany** Department have shown that the higher grain yield of Proctor and Herta barleys compared with Plumage Archer is due not to higher net assimilation rate, leaf area or total production of dry matter but to movement of a larger fraction of the total product of photosynthesis into the grain. Another and more striking example which suggests that the efficiency of the photosynthetic mechanism cannot be much increased, if at all, by breeding and selection for the improvement of yield is provided by a comparison of wild and cultivated beets. Some wild beets were found to have net assimilation rates identical with that of Kleinwanzleben E, the highest yielding strain of sugar beet.

In the weed studies it was reported last year that there were indications that the population of viable wild oat seeds decreased rapidly under temporary ley. Although this is true in the first year or two, further work has shown that the decrease is not maintained. This raises doubts about the efficacy of temporary leys for the eradication of wild oats, although they reduce the population. It has been found that low temperatures favour germination of wild oat seeds, but short exposure to warm conditions tends to break dormancy and to increase germination on return to low temperature. Other lines of work deal with trace elements, nutrient uptake by excised roots, the physiological effects of virus infection and the effect of time of application of nitrogenous fertilizers to barley.

The main work in the **Biochemistry** Department is, as before, an examination of the nature of various enzyme actions that seem relevant to biological problems. The enzyme from bracken that destroys vitamin B, and so plays a part in bracken poisoning, can be made in a stable form, and improved methods for following its action have been devised. Two substances generally classified as alkaloids have been made enzymically by purified enzyme preparations, and other enzymes have been used for fractionating and characterizing phosphorus compounds of varied origin. Some parts of the enzymic process by which some plant viruses lose their infectivity when stored in the laboratory have now been unravelled, thus providing a rational basis for making stable preparations and for beginning the attack on the mechanism by which infection takes place in susceptible hosts. The same problem is also being approached from the other side by studies on the relationship between the photosynthesis activity of plants and the readiness with which they become infected. With tobacco mosaic virus, at any rate, the whole virus particle is not essential for infectivity, but a low and evanescent level of infectivity is associated with fragments of it. This activity can be stabilized, but judgement is reserved on the claims that have been made elsewhere that infectivity can be created by combining initially non-infective fragments. Progress has been made in characterizing the potato-root eelworm hatching factor. More equipment for making leaf protein has been built or installed, and the production of about 100 lb. a week of stable, palatable solvent extracted protein should now be possible.

In the **Plant Pathology** Department further progress has been made in researches on the constitution and properties of viruses. Disrupting tobacco mosaic virus so as to separate the nucleic acid from protein suggests that infectivity may reside in the nucleic acid fraction and antigenic specificity in the protein. Methods for counting virus particles with the electron microscope were improved and used to study the fate of particles during the early stages of infection.

Spraying potato crops with persistent insecticides again decreased the incidence of virus diseases, especially leaf roll. Combined with roguing, this treatment produced vigorous seed stocks in England at a cost comparing favourably with the cost of buying new seed. Excising apical meristems from Arran Victory potatoes, a variety that is wholly infected with potato virus S, and culturing them first on agar, produced virus-free clones.

Five viruses infecting leguminous plants were identified, some of which were widespread in old stands of lucerne and long-established clover. Five viruses were also found infecting cereals and grasses; one does not appear to have been reported previously, but the others resemble viruses described in other parts of the world. How prevalent and important they are has yet to be established, but their existence raises the question whether some of the benefits from ploughing old leys and reseeding result from replacing virus-infected clovers and grasses with virus-free plants.

A new method of growing healthy sugar beet seed crops which economizes labour and gives scope for mechanization was designed and shows promise. Sugar beet was sown under barley and the stecklings left in the ground to seed in the following year. Weeds were controlled by spraying, and the seed plants were bigger and matured earlier than transplanted stecklings.

Potato blight was unusually severe in 1956, and copper fungicides increased yields at Rothamsted by 2 tons/acre; killing the haulm with sulphuric acid did not affect the proportion of tubers that became infected. Cultures of *Oospora pustulans* obtained from potato stems caused skin-spot when inoculated to tubers. Although this fungus can be contracted from the soil, the incidence of infection also depends on the extent to which the seed tubers are infected. In addition to surviving in the well-known skin-spot lesions, the fungus can infect eyes and sprouts, and is often present there on tubers showing no lesions. Despite the wet summer and exceptionally difficult harvest, wheat yielded well in experiments designed to control eyespot and take-all; by early sowing on uninfested land yields up to 56 cwt./acre were obtained. The yield responses to changes in certain agricultural practices, such as rate and date of sowing and manuring, depend greatly on whether the land is infested with the fungi that cause eyespot and take-all.

In the **Nematology** Department special attention has been paid to bud and foliar nematodes (*Aphelenchoides*), species of which attack mushrooms, and a wide range of higher plants. A new species of eelworm, also non-cyst-forming, which attacks oil palm has been described, and the knowledge of the host ranges and morphology of several species of root-knot eelworms has been extended by means of glasshouse tests. Cyst-forming eelworms have also received attention, and population studies of several types of these are in progress. A survey of experimental sites at Rothamsted and Woburn has revealed that there is a general infestation of potato-root eelworm at Woburn which has affected the potato yields of some field trials. Work, in collaboration with the Biochemistry Department, on the nature of the hatching factor given out by potato roots, is continuing. The existence of types of potato-root eelworm capable of attacking eelworm-resistant potatoes bred by crossing with the wild type, *Solanum andigenum*, has been confirmed. These biotypes occur in widely scattered localities and complicate the breeding of resistant varieties. Work has begun on the factors affecting the hatching of eggs from cysts of beet eelworm, and the movement and activity of larvae in soil. This study is of importance in that it is concerned with the first phase of attack upon plant roots. Work is also in progress on the morphology of

the cabbage-root eelworm and upon certain insect predators that feed on the cysts. A visiting Canadian worker has reviewed the taxonomy of a family of nematode parasites of insects and has studied species of nematode parasitic in fruit flies.

In the **Insecticides** Department the various factors which affect the toxicity of insecticides are being studied. It is influenced, for instance, by temperature, and the effect of changes of temperature on speed of action differs for the various insecticides. Further work has been done on the mechanism of action of the important group of organo-phosphorus insecticides. It is known that they affect choline esterase, and a comprehensive study is being made of this enzyme as it occurs in insects. There is evidence, however, particularly from experiments on the poisoning of insect eggs, that other processes may also be involved. A study is also being made of what happens to insecticides in the soil and how long they persist. It was shown that BHC (benzene hexachloride) does not appear to penetrate the soil beyond the depth to which it is mechanically incorporated, and that it disappears rapidly in summer but not in winter. The effect of plant-protection chemicals on beneficial insects has been further investigated and techniques devised for diagnosing cases of poisoning in bees and the nature of the poison. In collaboration with the National Agricultural Advisory Service the control of wheat-bulb fly is being studied and a search made for promising chemicals. Improvements have been made in biological methods of testing insecticides, and methods of application are being studied. Some work has been done on fungicides, and it has been shown that the systemic fungicide griseofulvin applied to the soil reduces club-root in cabbage, but applied to the foliage it has no effect.

In the **Entomology** Department new developments include regular surveys of Rothamsted and Woburn farms for pest insects. This will enable those carrying out experiments either to make proper allowance for insect attack if it affects yield or to adopt control measures at the earliest possible stage. Work has also been started on the influence of climatic factors on insects, both in the field, where effects of microclimate on growth are being studied, and in the laboratory, where particular attention is being given to the relations between fat metabolism and temperature. The work of trapping aphids and other insects with suction traps at different altitudes has now reached a stage where the results have considerable importance in explaining general problems of the periodicity of insect attacks, and the results may also be applicable to animals other than insects. New work on the wheat-bulb fly includes laboratory experiments on the reactions of larvae to plant exudates, which may help to explain how the larvae locate host plants and why certain plants are preferred to others. In a field experiment the rate of emergence and survival of the flies was studied in a natural population confined in a large cage. Much of the other work, though no less important, is a continuation of investigations started in previous years. Broadbalk was sampled for wheat-blossom midges for the thirtieth year in succession; the relationships of the midges causing seed losses in red clover, and therefore of potential economic importance, continue to be investigated. The importance of earthworms in marginal land and orchards is being studied, and work

continues on the effect of ants and of predators on aphid populations. The rate of decay of leaves and the production of litter is being studied in Knott Wood, using leaves marked with radioactive tantalum.

The work of the **Bee** Department has largely followed the lines of previous years. Further studies have been made on the nature of " queen substance " and on its collection and distribution by members of a colony. It has been shown that, despite suggestions to the contrary, the " queen substance " which worker bees receive in regurgitated food from other workers is sufficient to inhibit development of their ovaries, in the absence of a queen. Research has also been done on the process known as " queen supersedure " by means of which a colony replaces its queen without swarming. It has been concluded that shortage of " queen substance " is the only immediate cause of this, and that other factors such as disease or injury of the queen, which may initiate this process, do so by reducing the queen's output of this substance. It has also been shown that small quantities of mammalian hormones, such as androsterone and testosterone, as well as extracts of queen wasps and queen ants, when given to worker honeybees, inhibit development of their ovaries under conditions in which they would otherwise develop. In connection with swarming, comparative studies have been made of the salivary glands of worker bees both in and out of the swarming season, and changes have been noted in the degree of activity of these glands at different times of the year. Observations on the transmission of food throughout a colony indicate that workers receive food from bees older than themselves and give it to bees younger than themselves.

On bee diseases a very important advance has been made in the study of European Foul Brood. *Streptococcus pluton*, an organism suspected of causing the disease, has been isolated in pure culture, and it has been found that this organism and *Bacillus eurydice* have both to be present in a larva to cause the disease. By feeding a very small amount of the ammonium compound, di-*n*-decyldimethylammonium bromide, in syrup the disease has been controlled in small-scale experiments, and large-scale trials are now being made of this simple and economical treatment. Further work has also been done on Nosema and acarine diseases.

In the **Statistics** Department, the electronic computer is now working to full capacity. The capabilities of the machine have been increased by the provision of a high-speed tape reader and a punched-card reader. Programmes are now available for the routine analysis of all the commoner types of experimental design, and the number of variates analysed during the year has risen to over 1,700. Construction of these and other programmes has been facilitated by use of an automatic programming routine.

The results of several long-term Rothamsted experiments have been analysed. These include the four-course rotation on organic manures and forms of phosphate, the Woburn ley–arable and the large series of sugar-beet experiments. Close collaboration with the National Agricultural Advisory Service has been maintained on the design of crop and animal experiments. There has also been collaboration with the Galton Laboratory, the Blood Group Refer-

ence Laboratory, the Institute of Animal Genetics and the Animal Breeding Research Organization on genetical problems. Ten counties or part counties were surveyed in the survey of fertilizer practice during the year, and a nation-wide survey of cattle diseases has been continued in collaboration with Weybridge. A survey of mortality in pregnant ewes has been completed and is being written up. Research work on experimental design and methodology has been continued.

The **Field Experiments** Section and **Farm** staffs again dealt with over 3,000 experimental plots at Rothamsted and Woburn. A very difficult harvest for cereal plots was greatly helped by the combine harvester, and no plots were lost, although the grain came in with very high moisture contents. The liming programme for the correction of acidity on certain parts of the classical experiments is now complete, and Hoosfield, in particular, showed marked benefit on some of the very acid plots. In the mangold and sugar-beet experiment on Barnfield the dry weather conditions at time of sowing led to a spectacular difference in plant establishment and early growth between the dunged and fertilizer plots, especially those receiving sulphate of ammonia. This is probably attributable to differences in organic matter and acidity. The recent short-period experiments include an examination of the relative responses of sugar beet and potatoes to several levels of farmyard manure. Dung from the same source is used for both crops, which are situated alongside in the same field. Dung × fertilizer interactions are also measured, as are residuals in the following barley crop. In another short-term experiment in co-operation with the National Institute of Agricultural Botany and repeated at Woburn, the cropping capacity of autumn- and spring-sown beans is compared; three levels of phosphate and of potash in all combinations are tested, and also insecticides against aphids. An account is given of the wheat and fallow experiment started in 1856, and from this it appears that a three-year fallow is practically no better than a single year. A short historical summary is also given of the clover plot (in the garden of Rothamsted Manor), which has been cropped continuously with red clover since 1854.

At Woburn the classical plots are being cleaned by fallowing reinforced with TCA (sodium trichloroacetate), which appears to be a promising treatment against the twitch that is such a serious weed on these old plots. The potato test crop in the ley–arable rotation has been changed to sugar beet on account of potato-root eelworm, and one of the fields at Woburn has been assigned to eelworm research. The farm is being used to an increasing extent for short-term experiments, chiefly on the light soil, but now for certain crops, such as beans, on the clay land. The season was unfavourable for the most sensitive exotic crops, such as maize, which gave only about half the yield of previous years, but sweet lupins, serradella and a new German variety of Jerusalem artichoke did at least as well as usual. In the wet summer the irrigation experiment gave small responses to watering, but during the spring drought there were marked benefits to the barley and the May cutting of the cocksfoot ley.

PHYSICS DEPARTMENT

H. L. Penman

Professor Toogood returned to the University of Alberta in September; Dr. M. Dagg spent four months, based on the department, before going to the East African Agriculture and Forestry Research Organization; Mr. P. F. Noble, of the New Zealand Department of Agriculture, came in March to spend two years with us, and Dr. R. L. Davidson, of the University of Johannesburg, came in September for six months with a Nuffield Fellowship. D. A. Pearce returned from National Service and resumed duties in January.

G. H. Cashen, W. W. Emerson, Margaret Dettmann and H. L. Penman, with Professor Toogood and Mr. Noble, attended the Soils Congress in Paris. J. L. Monteith was the British delegate to a UNESCO meeting in Australia surveying problems in arid zone micrometeorology, and spent a few days before the meeting at the Soils Division of the Commonwealth Scientific and Industrial Research Organization, Adelaide, and a few days after the meeting at the Meteorological Physics Division, C.S.I.R.O., Melbourne.

H. L. Penman is being asked by the Food and Agriculture Organization to act as co-ordinator of a project for co-operative research in irrigation in western Europe.

Soil Physics

Electrical charges on clay (G. H. Cashen)

Further work on the electrical charges carried by kaolin has shown that a suggestion made in the 1955 report should be modified. In treating kaolin with cetyl trimethyl ammonium bromide (CTAB) two sets of data are obtained: a CTAB/pH titration curve of the suspension which normally shows two straight sections meeting in a bend; and a direction of endosmotic flow of electrolyte in a paste when a d.c. voltage is applied. It had been found that the amount of CTAB necessary to cause reversal of the endosmotic flow was independent of the initial pH of the kaolin suspension, and equal to the critical amount required at pH 4 to neutralize the planar charge, as judged from the position of the bend in the titration curve. It is now known that, because of edge-to-face flocculation (of which we have an electron micrograph for kaolinite), the planar faces cannot always be completely accessible to the CTAB: only if the positive edge charges are neutralized by sufficient pyrophosphate or oxalate can the full planar charge be measured by the two standard techniques. When this edge neutralization is achieved the value of the planar charge so measured is constant in the range pH 3–7, and thus represents the permanent isomorphous replacement charge. It has the same value as the cation-exchange capacity measured by the method using neutral ammonium acetate.

In the absence of dispersing agents the charge measured by the

titration near pH 4, and by the endosmotic technique, is more closely associated with the minimum possible net negative charge, i.e., with an upper limiting value of the positive charge on the edges. The latter can be produced in the endosmotic test because the paste round the anode becomes acid in the process of electrolysis. This suggestion of a maximum possible edge charge is in agreement with the results of H. R. Samson (*Rep. Rothamst. exp. Sta. for* **1952**) on the buffer capacity of kaolins, which showed that the net negative charge on the clay reached a limiting value at low pH.

There is thus a difference between the critical amounts of CTAB taken up by the planar faces in the absence and presence of a dispersing agent. If it is assumed that this difference is a measure of the maximum positive edge charge it becomes possible to estimate the area of the edges, because theoretical value of the maximum charge density, based on crystal structure, has been given by R. K. Schofield and H. R. Samson. Calculated values for Merck and Peerless kaolins give the edge areas as 12 and 19 per cent, respectively, of the total areas; these are of an acceptable order of magnitude and permit a more accurate calculation of the planar charge densities.

The decrease in cation-exchange capacity that occurs when kaolins are heated to various temperatures is being investigated by means of the CTAB techniques.

A full account of this work is almost ready for publication.

Soil structure (W. W. Emerson and M. Dettmann)

Synthetic soil conditioners

It has been shown that the concentration of carboxylated polymer needed to stabilize Na–montmorillonite gels in water is extremely small, too small for X-ray examination to reveal conclusively that the polymer is not linked to the basal silicate sheet. An optical technique is helping to resolve this difficulty. If thin sections of oriented flakes of Na–montmorillonite are immersed in dilute salt solutions they swell laterally and vertically. When viewed on the stage of a polarizing microscope, bands are observed near extinction, and if the small amount of polymer added to the clay does form an inter-lamellar complex, then the stabilized crystals will be visible perpendicular to the bands. Measurements of the dimensions of swollen flakes of Na–montmorillonite, with and without carboxylated polymer, have been made at various values of pH over a range of decreasing salt concentrations. The relation between lateral and vertical swelling as sodium-ion and hydrogen-ion concentrations are changed shows some signs of order, unexpected and perhaps fortuitous, but indicates that the process of deflocculation that occurs as the salt concentration is reduced might be caused by breakdown of linkages at the edges of the crystals. This is in conformity with other evidence that the carboxylated polymers form peripheral complexes with the Na–clay.

Sodium saturation test

The difficulty referred to in last year's report has been overcome and the test itself simplified. While the clay was supported by

sintered glass there was trouble if the clay dispersed and blocked the pores of the sintered glass. Now a layer of glass beads (½–1 mm. diameter) is used to support the crumbs, and only one concentration of NaCl is used, sufficiently high to prevent deflocculation of all unstable clays. The crumbs are now wetted under suction with 50 mN. NaCl solution, and the permeability measured using the same solution, which is then allowed to percolate for 24 hours before the permeability of the crumb bed is measured again. The decrease in permeability is a measure of crumb instability; tests on soil from the 80 plot of Barnfield (calcareous, unmanured and continuously arable) show a drop to very near zero permeability, whereas crumbs from an adjoining area of permanent grass have shown no change in permeability.

Soil structure field experiment

The last set of four-year-old grass and lucerne plots was ploughed up in the autumn of 1955; these and two control strips which had been fallow for the four years were sown in the spring with beetroot and carrots. The fallow strips were split for 3 levels of K and 2 levels of N; the higher level of N and an intermediate level of K being applied to the ley plots. After sowing there was a prolonged dry spell. The beetroot germinated very much better on the fallow plots and on the lucerne plots than on the grass plots, resulting in a 20 per cent increase in stand after singling. This is ascribed to the more rapid drying out of the surface soil on the grass plots, as the cultivations necessary to produce an adequate tilth on the fallow strips had left a very "fluffy" tilth on the ploughed-up grass. The carrots germinated more quickly than beetroot, and uniformly over the whole area. There was, however, a spectacular increase in the rate of growth of the carrots after the grass compared with the fallow and lucerne plots. This could be due to easier penetration of the tap roots into the grass plots. By the end of the summer, although differences were still visible, the total mean yield of roots from the grass plots—28 tons/acre—was only 4 tons/acre greater than from the fallow. The difference in saleable roots was even less marked, because of the much greater number of fanged roots after grass; which, it is suggested, is due to microbiological attack of the growing tip. There was no response to N on the fallow, and only a slight response to K, as judged by root yield. For beetroot the additional N on the fallow increased the yield from 5·8 to 7·8 tons/acre; but there was no response to K. There was a parallel increase in yield from 5·6 to 8·3 tons/acre between the hayed plots and the repeatedly cut plots (to simulate grazing), which may also be an N effect. The weight per root was higher after the grass.

The yields of the second test crop on the second block (autumn wheat after spring beans) were the same from the former fallow and grass plots, but the lucerne plots yielded an extra 5 cwt./acre grain. These results are in accord with the previous year's results on the first block. This block had spring barley as the third test crop. The barley on the old grass plots was more severely attacked by wireworm than that on the old fallow plots, but recovered sufficiently to give a slightly higher yield.

Agricultural Meteorology

Micro-meteorology

(a) *Continuous recording* (I. F. Long)

Temperature, humidity and wind measurements have been made among and above potatoes and wheat throughout the summer. We now have five years' data for potatoes, and these should be sufficient to answer questions about the environment of the growing plant. The instrument for recording dew-point temperature gradients has been made more precise, and we now accept its indications with considerable confidence. During its use in the potato crop it has registered periods of dew formation of short duration, and also occasions of very slight dew formation not detectable by other instruments. It has also shown that on some occasions the routine meteorological report of " observed dew " has in fact been reporting guttation, dew formation being impossible during the night before. Leaf temperatures at two levels, and soil temperatures at two depths have been continuously recorded and shown the same general behaviour as in 1955. Out of these observations, and those on wheat, we are gradually building up a coherent picture of the physics of the heat and vapour exchanges between soil and plant environment and free atmosphere.

A full account of the instruments has been written and submitted for publication.

Similar equipment has been used in spring wheat without introducing the variable of plant density. A telescopic support was used so that all observations above the crop were taken at fixed height intervals above the top of the crop. Detailed analysis of the two years' records is well advanced, and, among other information, has indicated that during part of the day the dominant controller of evaporation rate may be turbulence, and at others it may be radiation. For a short period soil temperature was recorded under the wheat at eleven depths 0–10 cm., and the temperature profiles show a very nearly constant temperature gradient (i.e., constant heat flux) at the surface throughout the night.

New equipment built, tested and ready for use, includes a slowly acting anemometer for long-period continuous recording of the low wind speeds characteristic of night conditions in the field. It is a " hot-wire " instrument using a helix of heated wire co-axial with, but not touching, a small cylindrical nickel thermometer. Its working range is 5–70 cm./sec.

(b) *Heat and water balance* (J. L. Monteith)

The main experiment planned for summer 1956 was not started because the special weighbridge was not ready in time. Considerable progress has been made in building auxiliary equipment, and in analysis of existing records.

Heat flux plates, to measure the rate of heat transfer in the soil, have been tested in a variety of granular materials of different thermal conductivity, both air-dry and saturated with water. Using plates $9 \times 2 \times 0{\cdot}16$ cm., the responses to a constant heat flux over a range of moisture contents have varied by ± 8 per cent in our

Rothamsted clay, but only by ±2 per cent in the Woburn sand. The cause of the variability is not known, but assuming that it may be a reflexion of particle size and the physical contact between soil and flux plate, a change in design is being considered.

In the field, the flux plates have been set under potatoes, wheat and grass, and the sensible heat flow and storage compared with the net radiation received, as measured by the radiometer described in last year's report. On calm nights, with the top-soil wet, the net radiation loss was almost completely accounted for by the sensible heat transfer through and from the soil, implying that dew formation, if any, should be attributed to vapour transfer from soil to leaf, rather than from air to leaf. (Some of Long's measurements of vapour-pressure profiles indicate the same bias, though not so markedly.) During one cloudless period of 24 hours at the end of July the net heat stored beneath all three crops was approximately 10 per cent of the net radiation received during the period; but in more normal cloudy weather, when soil temperatures showed little day-to-day variation, the net storage was only about 2 per cent of net radiation, or less. This heat-storage term is usually neglected in the estimation of evaporation rate from weather data, and it is clear that the neglect is justified in all but exceptional circumstances.

One of the factors in the energy balance out of doors, affecting evaporation estimates among other things, is the "albedo" or reflexion coefficient of the surface. Data on reflexion are very scarce, and it has been necessary to assume a value—round 20 per cent—much the same for all covers that look about the same colour. A small solarimeter incorporating a Hatfield heat-flux disc has been built and used to measure the reflexion coefficient of different crops. Tests over grass showed a nearly constant value of about 21 per cent throughout the day; but over a young crop of spring wheat the reflexion coefficient varied from 14 to 20 per cent with decreasing solar altitude. At the time, the soil was visible between the rows, and it appears that with a high sun more radiation was reflected from the soil (albedo about 13 per cent) than from the vegetation (albedo about 20 per cent). The usual method of measuring albedo by taking upward-facing and downward-facing readings on the same radiometer is inconvenient over tall crops, and is unreliable, anyway, if variable cloud causes radiation intensity to change rapidly. A simple double unit has been designed, and a first model built, of two arrays of thermocouple elements back to back, and with one looking at the sky and the other at the ground a potentiometer can give instantaneous measurements of albedo.

Measurement of high humidities. Under "*Miscellany*" in last year's Rothamsted Report reference was made to a method of measuring relative humidities close to 100 per cent. In collaboration with P. C. Owen (see Botany Department report) progress has been made. When current is passed through a bismuth–chromel junction (in the right direction) sufficient cooling can be produced at the junction to condense water from air at or above 98 per cent relative humidity, and the junction can then be used as the "wet-bulb" of a psychrometer. Used as such, the wet-bulb temperature is a linear function of the relative humidity between 98 and 100 per cent, and in this range the humidity can be estimated to better

than 0·1 per cent. It appears to be a useful way of measuring high humidities, especially in small enclosed spaces and, as Owen reports, has made possible the measurement of equilibrium relative humidity of small soil samples. Temperature stability is absolutely essential, and there is little prospect of the method being much use in the field.

Soil water and soil temperature (P. F. Noble)

Some of the work of J. S. G. McCulloch (*Report Rothamst. exp. Sta. for* **1953**) was presented in a paper, read at the Paris Soils Congress, which discussed the theory of heat flow in a soil with marked heterogeneity. The available records were too coarse, and the number of sunny days too few, for the check of the theory to be completely satisfactory, and an artificial source of " sunny " days has been built. A patch of bare soil—close to McCulloch's working site—has been heated from above by a heating mat controlled by a cycling mechanism that gives a periodic change of energy input of adjustable amplitude. After initial difficulties it is now working. Miniature nickel resistance thermometers (given a trial run in Long's experiment) are buried at depths from the surface to 40 cm. below, and continuous records taken from them. Heat-flux plates have also been buried. First records are promising, and are now being analysed.

After a visit to the Atomic Energy Research Establishment, Harwell, components have been bought for the construction of equipment to measure the scattering of neutrons in soil. The extent of this scattering is uniquely dependent on the water content of the soil, and application of this technique of measuring soil-water content should help in several kinds of research and technical problems.

The first steps have been taken in the study of the movement of the transpiration stream through the plant. American experiments have shown promise, the technique being to introduce heat at one region of the stem, and measure the rise, and rate of rise, of temperature a short distance above.

Evaporation

Application of previous work has continued, by ourselves and by others at home and oversea. The only minor advance has arisen in a private communication to the Swiss Forestry Service commenting on the hydrology of the two catchments (Sperbelgraben and Rappengraben) that have been gauged for about fifty years. Both are very steep valleys, and it was necessary to calculate the effect of slope on evaporation. For these valleys, with a slope of about 23° and a south-westerly exposure the estimated increase is about 18 per cent in midsummer, 100 per cent in midwinter and 28 per cent over the year, as compared with a flat area.

Irrigation at Woburn

P. F. Noble has installed transpiration gauges in an irrigated and in a control plot on the grass area. There was too much summer rain for anything useful to emerge from the first season's work.

A start has been made on the analysis of the six years' data now

available from Woburn. A close-to-linear relation has been found between the accumulated growth of grass expressed as dry matter, and the accumulated effective potential transpiration, the integrations extending through the winters as well as the main growing periods. It seems clear that, apart from increasing yield, one of the beneficial effects of nitrogen fertilizer is to increase the drought tolerance of the grass in the sense that plots with higher nitrogen dressings can build up a larger soil-moisture deficit without a check to growth than plots with less nitrogen. This work is essentially exploratory, but it is encouraging to find some sign of order in crop–weather relationships.

On the whole, the first six years of work at Woburn have been carried out in average to wetter-than-average summers. A summary table follows, showing the results of the maximum irrigation on each crop in each year, some of the maxima being greater than would be recommended for farming use: this is an experiment. The yields are means of two fertilizer treatments and are given in two columns: O, the control plot, not irrigated; C, the maximum irrigation plot. Under I is the amount of irrigation applied to the C plots. Under "Rain" is a coarse indication of the rainfall in each of the summer months April to September.

Irrigation Results at Woburn up to End of Second Three-course Rotation

		Barley			Grass			Sugar beet			Potatoes		
Year	Rain	Grain, cwt.		I, in.	Dry matter, cwt.		In.	Sugar, cwt.		I, in.	Tons		I, in.
	A M J J A S	O	C		O	C		O	C		O	C	
1951	w A D D W W	26	31	3·2	43 *	53	3·6	50	54	3·4	4 †	8	2·2
1952	A A D D W W	22	25	2·9	55	86	5·1	51	59	5·6	6	10	2·7
1953	w A A W d A	27	26	0·8	89	100	5·6	84	82	3·6	11	13	2·0
1954	D A W W W A	34	35	1·8	33 *	30	2·9	45	45	1·2	16 †	15	2·2
1955	D W A D D d	36	36	1·4	46	73	7·7	34	48	6·4	11	20	6·3
1956	D D A W W A	29	32	2·6	68	85	3·9	64	60	1·4	15	15	0·5

A = average ± <0·5 in. $\frac{W}{d}$ = average ± 0·5–1·0 in. $\frac{W}{D}$ = average ± >1·0 in.

* Newly sown—grass/clover 1951–53, S.37 cocksfoot 1954–56.
† Earlies 1951–53, Maincrop 1954–56.

Woburn irrigation 1956

After a dry spring, the summer was very wet, and except for one fortnight in June there was no need for irrigation after the end of May.

Grass. The first two cuts showed the effect of irrigation in May and account for the whole of the difference between O and C in the final totals.

Sugar beet. The stand was good, but as the main need for water came after the drought very little irrigation was called for.

Barley. The effect of spring watering was very marked in the early growth. From June to harvest the differences gradually disappeared.

Potatoes. Little need, and little response.

The table gives the responses to full irrigation (C plots) designed to keep the plots near field capacity throughout the summer, at two levels of nitrogen fertilizer dressing (N_1 and N_2) imposed on the standard P and K dressing appropriate to each particular crop.

Woburn Irrigation 1956

Crop	Period	Rain, inches	Irrigation, inches	Plot	Yield
Grass	30 Apr.–1 Oct.	13·2	—	ON_1 55·2 ON_2 81·1	Dry matter, cwt./acre, 6 cuts
			3·9	CN_1 71·9 CN_2 99·0	
Sugar beet	30 Apr.–1 Oct.	13·2	—	ON_1 60·3 ON_2 67·4	Sugar, cwt./acre
			1·4	CN_1 55·3 CN_2 65·2	
Barley	30 Apr.–30 July	6·9	—	ON_1 26·1 ON_2 31·2	Grain, cwt./acre
			2·6	CN_1 29·1 CN_2 34·7	
Potatoes	30 Apr.–1 Oct.	13·2	—	ON_1 14·2 ON_2 15·7	tons/acre
			0·5	CN_1 14·8 CN_2 16·0	

Because of eelworm infestation, potatoes will be excluded from the next rotation, to be replaced by beans. Spring wheat will probably replace the barley.

CHEMISTRY DEPARTMENT

G. W. Cooke

R. K. Schofield resigned on 14 January to take up the appointment of Reader in Soil Science at the University of Oxford. G. W. Cooke was appointed to succeed him on 1 March 1956.

A. W. Taylor resigned at the end of July to take up an appointment at Pennsylvania State University; W. F. Roue resigned in March and A. Stephens resigned at the end of the year.

J. K. R. Gasser joined the staff in October; J. M. d'Arifat, G. H. Owen and R. J. B. Williams were appointed to carry out analytical work.

P. W. W. Daborn of the Forestry Commission was seconded for a further year for work on nutrition problems in forest nurseries. Several members of the Colonial Agricultural Research Service were trained in the Department in soil-fertility work and field experimentation. J. C. Chisnall worked in the Department in the spring before going to British Guiana; R. K. Cunningham left in September to take up an appointment at the West African Cocoa Research Institute; A. Pinkerton completed his training at the end of the year and was appointed to the Department of Agriculture, Kenya; R. Webster joined the Department in November.

Dr. T. Harada from The National Institute of Agricultural Sciences, Japan, worked with J. M. Bremner on soil-nitrogen problems for six months. Professor S. W. Melsted from the University of Illinois came in September to spend a period of sabbatic leave. Mr. P. Kivinen of the University of Helsinki, Mr. L. Overrein of the Agricultural College of Norway and Mr. C. Bishop of Reading University all worked in the Department for several weeks.

P. W. Arnold was seconded to work at the West African Cocoa Research Institute for a year. S. G. Heintze was granted a year's leave of absence to work at the Galloway Laboratory, Hamilton, New Zealand.

G. W. Cooke, S. G. Heintze, G. E. G. Mattingly, K. Shaw and R. G. Warren attended the Sixth Congress of the International Society of Soil Science held in Paris.

Fertilizer Placement

(G. W. Cooke, F. V. Widdowson and A. Penny)

A small series of field experiments which compared broadcasting and placing of separate nutrients for a number of crops has now been concluded.

In twelve experiments on potatoes carried out since 1953 gains from placing ammonium sulphate and potassium sulphate beside the seed, as compared with broadcasting these fertilizers on flat land before planting by machine, have been examined. In each year there have been marked and consistent increases in yield from placing over broadcasting for each nutrient at the lower rates of

application used (0·5 cwt. N and 0·75 cwt. K_2O/acre). Gains from placing the higher rates (1·0 cwt. N and 1·5 cwt. K_2O/acre) of both nutrients were smaller and less consistent. The results of the experiments emphasize the special value of placement when fertilizer dressings are restricted. There is no case for separating the components of a mixed fertilizer and applying part placed and part broadcast.

Further experiments on broad beans and peas were carried out in 1956, both crops being picked green for market. Superphosphate and muriate of potash and a mixture of the two fertilizers were broadcast and worked into the seedbed and compared with dressings placed in a single band beside the seed. The effects of broadcasting P, K and PK fertilizers on yields of broad beans were small and irregular. When the dressings were placed there were large increases in yields of beans from phosphate and potash applied separately and together. The experiments also tested a complete NPK fertilizer; there was no worthwhile gain from the addition of nitrogen. These results confirm those of a similar experiment on broad beans carried out in 1955. In the 1956 experiment on peas there were no gains from the fertilizer dressings, however applied. The two years' work suggests that benefits from placing a PK fertilizer beside the seed, demonstrated in earlier experiments on peas and beans, were due to both the phosphorus and potassium components of the mixture. The work also emphasizes that tests of broadcast fertilizers for peas and beans may give misleading impressions, since much larger yield increases are obtained by placing the fertilizers beside the seed.

Combine-drilling potassium fertilizers for cereals

Comparisons of combine-drilling and broadcasting of potassium fertilizers for spring-sown barley were continued in 1956. Four experiments compared fertilizers broadcast and harrowed into the seedbed with combine-drilled dressings. At each centre a single dose of potash (0·25 cwt. K_2O/acre) when combine-drilled gave higher yields than twice as much potash broadcast. At three of the four centres combine-drilling the double dressing gave higher yields than drilling the single dressing.

Methods of Application and Rates of Nitrogen Fertilizer for Cereals

Winter wheat (F. V. Widdowson)

Four experiments were carried out on three varieties of stiff-strawed winter wheat to compare two rates of " Nitro-Chalk " applied as a spring top-dressing. There were good responses to nitrogen in each experiment, at two centres 4 cwt./acre of " Nitro-Chalk " was sufficient for maximum yields, at the other two centres the highest yields were given by 8 cwt./acre. There were no gains at any centre from splitting the nitrogen dressing and applying 1 cwt. of " Nitro-Chalk " in autumn, the remainder being applied in spring. On average of all the centres Hybrid 46 gave the largest

response to nitrogen, at the high rate of dressing Heine 7 was inferior to Hybrid 46. The unmanured yield of the third variety, Minister, was higher than those of the other two varieties, but it gave much smaller responses to " Nitro-Chalk " at both rates of application.

Spring cereals (F. V. Widdowson, A. Penny and G. W. Cooke)

Fourteen field experiments on spring cereals have been carried out since 1954 to compare combine-drilling and broadcasting of ammonium sulphate and to measure the additional effects of top-dressings of " Nitro-Chalk " applied in May. The results are summarized in Table 1. There were ten experiments on barley and four on wheat. Generally barley gave much larger responses to nitrogen than wheat, but in this summary results on the two crops have been averaged. In three-quarters of the experiments combine-drilling gave a higher yield than broadcasting the dressing either on the seedbed or as a May top-dressing. The average gain from combine-drilling the heavy dressing was nearly 2 cwt. of grain/acre.

TABLE 1

Unmanured yields of grain (in cwt./acre) and the increases given by nitrogen fertilizers applied in different ways in experiments on spring-sown wheat and barley

Approximate dressing per acre :	1954	1955	1956	Mean	
				Yield	No. of positive effects
No. of experiments	4	3	7	14	14
Yield without nitrogen ...	24·8	25·5	15·8	20·4	—
Increase from 0·25 cwt. N/acre :					
Broadcast	2·6	5·7	6·4	5·2	13
Drilled	3·8	4·6	7·9	6·0	12
Top-dressed *	(2·0)	4·7	6·5	(4·8)	13
Increase from 0·5 cwt. N/acre :					
Broadcast	5·0	7·3	9·4	7·7	13
Drilled	6·8	9·6	11·0	9·5	14
Top-dressed *	(4·1)	9·8	7·8	(7·2)	13
Gain from drilling over broadcasting :					
At low rate	1·2	−1·1	1·5	0·8	10
At high rate	1·8	2·2	1·7	1·8	11
Increase from top-dressing plus seedbed dressing of :					
0·25 cwt. N broadcast ...	7·1	11·9	10·6	9·9	13
0·25 cwt. N drilled	8·0	11·1	11·4	10·3	14
0·5 cwt. N broadcast ...	7·8	12·7	10·8	10·4	12
0·5 cwt. N drilled	7·4	10·7	11·6	10·2	13

* In 1954 top-dressings were tested by applying 4 cwt./acre of " Nitro-Chalk " to split plots; the increases in yield given by top-dressing alone in 1954 have been determined by graphical interpolation of yields on plots with no seedbed dressing, and are therefore approximate.

There was a good average gain (2·7 cwt./acre of grain) from top-dressing given in addition to the heavy broadcast seedbed dressing, but in the presence of the drilled seedbed dressing, top-dressing

gave only a small additional yield (0·7 cwt./acre of grain) which would not be sufficient to pay for the extra fertilizer used. The effects of top-dressing varied. In the wet years of 1954 and 1956 top-dressings alone gave smaller average increases in yield than either broadcasting or drilling the same amount of nitrogen. In 1955, when the summer was dry, top-dressings and seedbed dressings gave similar increases in yield. In 1956 nitrogen top-dressings were much inferior to seedbed dressings in all experiments on barley. Crops on plots receiving top-dressings made very soft growth and produced much more straw than barley grown with seedbed dressings only. At harvest practically all top-dressed plots were badly lodged; on these plots the crop was much less mature and more uneven, and the quality of the grain was markedly inferior to that grown with seedbed dressings alone. These experiments suggest that top-dressing with nitrogen in May cannot be recommended for spring barley. Full yields have been produced by combine-drilling adequate amounts of ammonium sulphate with the seed, while top-dressings given in addition to drilled seedbed dressings have not produced worthwhile average increases in yield, and in wet years have made harvesting difficult and late and have reduced the quality of the grain. This work has been carried out in a restricted area of the Eastern Counties, and it needs to be extended to other corn-growing areas so that firm recommendations may be made.

Comparisons of Forms of Nitrogen Fertilizers

(F. V. Widdowson, A. Penny and G. W. Cooke)

Spring cereals

In two experiments on barley and one on wheat, combine-drilling and broadcasting of both ammonium sulphate and calcium nitrate were compared. Calcium nitrate gave slightly higher yields than ammonium sulphate when the fertilizers were broadcast; there was little difference between yields given by the two fertilizers when they were drilled. In the two barley experiments combine-drilling gave consistently higher yields than broadcasting when ammonium sulphate was used; with calcium nitrate broadcasting was slightly superior. In the wheat experiment broadcasting of both fertilizers gave higher yields than combine-drilling.

Potatoes

Eight experiments on main-crop potatoes tested 0·5, 1·0 and 1·5 cwt. N/acre applied as ammonium sulphate, calcium nitrate and urea. Average responses to nitrogen were smaller than have been obtained in recent years, and 1·0 cwt. N/acre was sufficient for maximum yields. At the low rate of dressing ammonium sulphate and calcium nitrate gave similar yields; at the medium rate (1·0 cwt. N/acre) calcium nitrate was slightly inferior. The heavy dressing of ammonium sulphate gave the same average yield as the medium dressing, but the high rate of calcium nitrate reduced yields markedly. At the light and medium rates of dressing urea was markedly inferior to the other forms of nitrogen, and at the highest rate it gave lower yields than were obtained on plots receiving no

nitrogen. At three of the centres fertilizers were broadcast over the furrows before planting by hand; at all rates of dressing urea checked emergence and early growth at these three centres, the effect being particularly serious at the high rate, where emergence was delayed by about a month and many plants were killed. The high rate of calcium nitrate also caused a check to growth, although the effect was less serious. Ammonium sulphate was quite safe. At the other five centres fertilizers were broadcast over the flat land before planting by machine, and early growth was not checked by urea or calcium nitrate; urea gave consistently lower yields than ammonium sulphate even at centres where there was no check to growth.

Kale

Two experiments on kale also compared ammonium sulphate, calcium nitrate and urea each applied at 1·0 and 2·0 cwt. N/acre. At one centre where the crop was grown on wide rows practically no plants germinated on plots dressed with urea, the heavy dressing of calcium nitrate also damaged germination, but ammonium sulphate was quite safe; the damaged plots were resown. At the other centre the kale was grown in rows 14 inches apart and the plants were not thinned; urea damaged germination, but sufficient plants emerged to give a satisfactory though thinner plant. At both centres ammonium sulphate gave higher yields than calcium nitrate at the low rate of dressing, but calcium nitrate was superior at the high rate; urea gave much lower yields than ammonium sulphate at both rates. These experiments also tested the effect of splitting the dressings of nitrogen fertilizers, part being applied before sowing and part as a top-dressing of "Nitro-Chalk" in summer. Split applications gave higher yields than dressings applied wholly to the seedbed when ammonium sulphate was applied at planting, but not when calcium nitrate was used.

The urea used in the experiments on potatoes and kale was an imported granulated fertilizer-grade material having excellent physical condition. It contained approximately 4 per cent of biuret, and it is thought that this constituent was responsible for damage to early growth and subsequent poor yields. Less-severe checks to early growth were also caused by calcium nitrate in the dry and cold spring of 1956, and it is possible that a part at least of the damage caused by urea was due to high salt concentrations which developed as this material decomposed. Damage to germination and early growth caused by urea was also observed in experiments on ryegrass; the crops recovered to give satisfactory takes of grass. In future work on urea samples free from biuret will be used.

Formalized casein for grass (K. Shaw and F. V. Widdowson)

Laboratory incubation experiments showed that formalized casein produced inorganic nitrogen at a slow and uniform rate, confirming the results of earlier work with this material in pot experiments (*Rep. Rothamst. exp. Sta. for* **1950**, 39, and **1951**, 39). Formalized casein was tested as a slowly-acting nitrogen fertilizer in a field experiment on newly-sown Italian ryegrass from which three cuts

were taken in 1956. The availability of the nitrogen in the formalized casein, as measured by the response, was compared with responses produced by three equal dressings of ammonium sulphate supplying the same total quantity of nitrogen. There was little benefit from the formalized casein at the first cutting, but at the second and third cuttings, yields compared favourably with those given by repeated dressings of ammonium sulphate. The experiment also compared single dressings of casein and ammonium sulphate with repeated dressings of ammonium sulphate, calcium nitrate and urea. Repeated dressings produced slightly higher aggregate yields than single dressings.

Field Experiments with ^{32}P-labelled Superphosphate

(G. E. G. Mattingly)

The results of a series of field experiments using labelled superphosphate which were carried out in collaboration with F. V. Widdowson over several years have now been summarized.

Radiation effects

Two field experiments were carried out on barley in 1954 and 1955 in which the initial specific activities were 0·62 mC and 0·36 mC/g. respectively. At an early sampling both yield and total phosphorus uptake were slightly lower on the plots receiving ^{32}P-labelled superphosphate than on plots where ordinary superphosphate was used. In 1955 (but not in 1954) these differences persisted at harvest. None of the effects which could be attributed to radiation were significant, although for both yield and phosphorus uptake at the early sampling they were greater than the appropriate standard error. In a 1954 pot experiment yield and total phosphorus uptakes by grain and roots were slightly greater where ^{32}P was applied than where ^{31}P was used, but none of the effects were significant. These results suggest that while effects due to the active isotope may occur in experiments using ^{32}P-labelled fertilizers, they are generally very small compared with the increases in yield and phosphorus uptake given by the main treatments. These conclusions are in general agreement with those of American workers.

Comparison of drilling and broadcasting phosphate

Four experiments on barley and five experiments on root crops (fodder beet, swedes and potatoes) were carried out from 1952 onwards. The effects were measured of broadcast dressings of ordinary superphosphate and other phosphate fertilizers containing ^{31}P on the uptake from a light, uniform dressing of ^{32}P-labelled superphosphate (applied at 0·1 cwt. P_2O_5/acre for barley and 0·2 cwt. P_2O_5/acre for roots). The active superphosphate was applied to all plots of the experiments. For both barley and for roots the broadcast inactive fertilizers increased yields and the *total* uptake of phosphate in the presence of the drilled active dressing. Measurements of the phosphorus taken up from labelled superphosphate showed that the amounts were reduced slightly by the presence of

the much larger broadcast dressings. These reductions amounted on average of all the experiments to only 7 per cent of the uptake of placed active phosphate for barley and 13 per cent for roots. Their magnitude suggests that moderate dressings of broadcast phosphate fertilizers have rather little effect on the uptake of phosphorus from a small dressing drilled close to the seed.

This point was further investigated in three other experiments on barley carried out from 1953 to 1955. The uptake of ^{32}P from broadcast dressings of labelled superphosphate applied at 0·2 cwt. P_2O_5/acre was measured in the presence and absence of 0·1 cwt. P_2O_5 as ordinary superphosphate drilled with the seed. On average of the three experiments there were only small increases due to phosphate, the mean recovery from broadcast superphosphate being only 8 per cent. Drilling the dressing of ordinary superphosphate had very little effect on the uptake from broadcast active superphosphate. These results all suggest that the uptake of phosphorus by barley from broadcast superphosphate is largely independent of the uptake from a simultaneous drilled dressing when low rates of application are used.

Residual effects of phosphates

An experiment previously described (*Rep. Rothamst. exp. Sta. for* **1955**, p. 46) was continued to measure the effects of residues of fertilizers applied in 1954 and 1955 on the uptake by ryegrass of phosphorus from a broadcast dressing of 0·5 cwt. P_2O_5/acre as radioactive superphosphate applied in spring, 1956. The results of the 1956 work are summarized in Table 2.

TABLE 2

Residual effects of phosphate fertilizers on ryegrass

	Yield of dry matter, cwt./acre	Total P in crop from soil and residues of fertilizers, cwt. P_2O_5/acre	*Extra* P in crop from active superphosphate applied in 1956, cwt. P_2O_5/acre
Without phosphate in 1954–5	69·3	0·388	0·165
Increases due to residues of 3·0 *cwt.* P_2O_5 *per acre applied as :*			
Superphosphate 1954 ...	5·7	0·133	—0·023
Superphosphate 1955 ...	6·6	0·204	—0·050
Gafsa rock phosphate 1954	3·5	0·067	0·001
Gafsa rock phosphate 1955	5·2	0·164	—0·031

The residues from superphosphate and Gafsa rock phosphate applied in 1954 and 1955 increased yields and phosphorus uptakes of ryegrass grown in 1956. Residues from 1955 dressings were more effective than those from corresponding 1954 dressings. The uptake of phosphorus from ^{32}P-labelled superphosphate given in 1956 was significantly reduced by residues from both superphosphate and Gafsa rock phosphate given the year before; Gafsa applied in 1954 had no effect.

Recovery of applied phosphorus

In experiments with unlabelled phosphates estimates of the amounts of the applied dressing which are recovered are open to

the criticism that the added phosphate so stimulates root growth that the crop takes up extra amounts of soil phosphate. These experiments with ^{32}P-labelled superphosphate have provided estimates of the percentages of the applied active phosphorus which have been recovered by crops grown on the Rothamsted Farm; they are not subject to errors due to extra uptake from soil phosphorus, and are therefore summarized in Table 3.

TABLE 3

Mean percentage recoveries of phosphorus from ^{32}P-labelled superphosphate in annual field experiments, 1952–56

Crop	Method of application	No. of experiments	Rate of application, cwt. P_2O_5/acre	Percentage recovery
Barley... ...	Drilled with seed	7	0·1	14
Barley... ...	Broadcast	3	0·2	8
Root crops ...	Placed near seed	5	0·2	21
Ryegrass ...	Broadcast	1	0·5	33

OIL-PALM EXPERIMENTS

(W. B. Haines)

Data from the oil-palm experiments discussed in last year's Report have been further examined. When manuring was stopped after many years there was an abrupt drop in the first year in bunch weight but not in bunch number, followed by a gradual decline of the potash effect at a rate similar to that at which it was built up. There were marked seasonal differences, the effect of P was to produce lower numbers of bunches in a dry season and an increased number in the early part of a wet season when yields were at their best. In contrast to this, K did not affect the bunch number in the early part of a wet season, but produced large effects in the remaining part of the year (i.e. the later wet season and the following dry season). Poaching between plots through root action was assisted where P had been given, due to the stimulating effect of this nutrient on root growth. It was necessary to correct potash deficiency before phosphate manuring gave good results.

Individual oil palms vary greatly in their yield capacity. Data have been examined to see whether fertilizer responses were related to palm classes in such a way that would make individual selective treatment desirable. The results show that all classes play their part in producing the return from manuring and that no class need be rejected in treating the data. Where high competition effects are suspected it might be economic to give increased dressings to the poorer classes of palm to help them withstand competition, rather than to concentrate manuring on the high yielders.

RESIDUES OF FERTILIZERS AND FARMYARD MANURE

(R. G. Warren)

An account of the changes in the total amount of soil organic matter in the Broadbalk and Hoosfield experiments and of the value

to barley of P and K residues from fertilizers and farmyard manure applied last century on the Exhaustion Land Experiment was presented to the Fertiliser Society this year. A new scheme for the cropping of the Exhaustion Land, together with proposals for the addition of P and K fertilizers to parts of the experiment, are being prepared in order to measure the effects of the P and K residues on six different crops grown in the same year and to compare these effects with those from new applications of P and K.

The study of residues of organic matter has been extended to include the Deep Cultivation Experiment and the Ley–Arable Experiments. In the Deep Cultivation Experiment the addition of a total amount of 60 tons/acre of farmyard manure applied to the root crops grown during two cycles of the six-course rotation raised the organic-matter content of the top 12 inches of soil by 0·1 per cent organic carbon; these small increases in organic matter were similar for both depths of ploughing (6 inches and 12 inches). The deeper ploughing caused an overall reduction of 0·2 per cent organic carbon both on plots receiving farmyard manure and also where no manure was given. The combined effect of deep ploughing and applying farmyard manure was a reduction of 0·1 per cent organic carbon. In the Four-Course Rotation Experiment 80 tons/acre of farmyard manure applied over a period of twenty-five years raised the organic carbon by 0·1 per cent. Similar increases were given by straw and straw compost applied at the same rate of organic matter as the farmyard manure.

Soil Nitrogen

Denitrification (J. M. Bremner and K. Shaw)

Work on the factors affecting loss of nitrogen from soil by denitrification was continued. A critical examination of the methods available for following nitrogen changes in soil under conditions favourable for denitrification showed that the salicylic acid modification of the Kjeldahl method to include nitrate was not satisfactory for use with wet soil and that oven-drying of wet soil caused extensive loss of nitrate, nitrite and ammonia. A modification of a method of determining total nitrogen, including nitrate and nitrite, described by Olsen (*C.R. Lab. Carlsberg*, **17** (*1929*), *No. 3*) was found to give very accurate and consistent results, and this procedure was therefore adopted to follow total nitrogen changes in soil under various conditions. An investigation of the effect of various organic materials on the denitrification of nitrate in mineral soils showed that carbon in the form of readily decomposable substances, such as glucose, mannitol or cellulose, caused much more rapid and extensive denitrification than did carbon in the form of straw, lignin or sawdust. Water-extracted straw and decomposed straw had much less effect than untreated straw, and carbon added in the form of finely ground peat or fen soil had only a small effect compared with that produced by an equivalent amount of carbon as straw. The effect of adding different amounts of readily available carbon was studied. The total nitrogen loss decreased with increase in the amount of carbon added because

carbon in excess of the amount required by denitrifying organisms for the reduction of nitrate to gaseous nitrogen stimulated the activity of nitrogen-fixing organisms. An investigation of the course of denitrification in soils treated with nitrate and different levels of glucose showed that the disappearance of nitrate was accompanied by the formation of considerable quantities of nitrite and small quantities of ammonia, and that the nitrite formed disappeared rapidly if the amount of carbon added as glucose was more than about twice the amount of nitrogen added as nitrate. Neither hydroxylamine nor hyponitrous acid could be detected at any stage in the denitrification process. Tests with hydroxylamine showed that it was immediately decomposed in Rothamsted soils by a reaction which appeared to be purely chemical. Experiments using $K^{15}NO_3$ showed that all of the nitrogen lost when nitrate and glucose were added to waterlogged soil was derived from the nitrate added. Further work on the effects of temperature and pH showed that the optimum temperature for denitrification is between 50° and 70° C. and that the low rate of denitrification in soils of low pH is not due to lack of calcium or molybdenum. Results so far obtained in experiments with soil at different moisture levels indicate that the degree of water saturation of the soil is of decisive importance in determining the rate and extent of denitrification. Below a certain moisture level no denitrification occurs; above this the rate of denitrification increases rapidly with increase in the amount of water present.

All the results so far obtained in this work support the view that denitrification occurs only under conditions when the supply of oxygen is limited. Claims that denitrification occurs even when the supply of oxygen is satisfactory could not be substantiated. For example, no loss of nitrogen could be detected when waterlogged soils containing nitrate and glucose were shaken in an atmosphere of oxygen or when moist soils containing nitrate and glucose were aerated continuously. From the practical aspect probably the most important conclusion reached is that no significant loss of nitrogen occurs if the water content of the soil is less than 60–70 per cent of the water-holding capacity, even if all other conditions are favourable for denitrification.

Mineralization of nitrogenous materials in soil (J. M. Bremner and K. Shaw)

The potentialities as slowly-acting nitrogenous fertilizers of various waste materials and of products prepared from such materials have been tested by determining the rate of mineralization of their nitrogen in soil under controlled conditions in the laboratory. Formalized casein and formalized hoof were found to release mineral nitrogen more slowly and uniformly than the unformalized materials. Deamination of casein had little effect on the rate of mineralization of its nitrogen. Products prepared by treating lignin with nitric acid and with nitrous acid released mineral nitrogen at similar rates and more rapidly than did lignin–ammonia complexes. Nitrated sawdust having a C/N ratio of 2·3 decomposed very slowly, and cellulose nitrate (C/N, 2·3) and amyl nitrate (C/N, 4·3) were resistant

to decomposition. This work indicates that nitrogen in the form of nitrate ester is not mineralized by soil micro-organisms and provides further evidence that the carbon : nitrogen ratio of a material is not a reliable guide to its value as a nitrogenous fertilizer. Experiments with crushed hoof confirmed other evidence (*Rep. Rothamst. exp. Sta. for* **1949**, 32) that there is no justification for the traditional view that hoof is a slowly-acting nitrogenous fertilizer. The results with formalized casein and formalized hoof confirmed indications from pot experiments that such products may be useful as slowly-acting nitrogen fertilizers, and the value of waste formalized casein from the plastics industry is therefore being tested in field experiments.

Lignin-like material in soil (J. M. Bremner)

Further work was carried out to test the theory that a substantial fraction of soil organic matter consists of nitrogenous complexes formed by reaction of lignin or lignin-derived material with ammonia or protein. An investigation of the properties of lignin–ammonia complexes showed that the reaction of lignin with ammonia causes little destruction of methoxyl groups or of the units responsible for the formation of aromatic aldehydes on oxidation with alkaline nitrobenzene and that most of the nitrogen fixed by lignin in its reaction with ammonia is resistant to treatment with hot acid or alkali. Incubation tests showed that the nitrogen in a humic acid preparation was mineralized in soil at a rate intermediate between that of nitrogen in the form of lignin–ammonia and of lignin–protein complexes. Continuation of work previously reported showed that the reaction of humic acid with nitrous acid resembles the reaction of lignin with nitrous acid and indicated that lignin or lignin-derived material may be largely responsible for the high apparent amino-nitrogen values obtained when humic acids are analysed for amino groups by the nitrous acid method of Van Slyke. The reaction of lignin with nitrous acid was found to be similar in many respects to its reaction with nitric acid. Most of the nitrogen liberated by acid hydrolysis of lignin–nitrous acid reaction products was identified as ammonia and hydroxylamine. Examination of the products formed on nitration and alkali fusion of humic acid preparations showed that humic acids, like lignins, yield 3 : 5-dinitroguaiacol on treatment with nitric acid in ether and yield catechol and protocatechuic acid on fusion with potassium hydroxide.

These results, taken with the previous finding that humic acids yield aromatic aldehydes (vanillin, syringaldehyde and *p*-hydroxybenzaldehyde) on oxidation with alkaline nitrobenzene (*Rep. Rothamst. exp. Sta. for* **1954**, 50), leave little doubt that soil humic acids contain some lignin-like material, but no conclusions can yet be drawn regarding the amount of lignin-derived material they contain.

Effect of storage on the biological activity of soil (J. M. Bremner)

The biological activity of soil samples taken from Plots 3 and 7 of Broadbalk in 1881 and subsequently stored in an air-dried condition in sealed bottles has been investigated. The results showed that these stored soils were unable to nitrify ammonium sulphate

but ammonified added organic nitrogen compounds and denitrified added nitrate more rapidly than did unstored soil taken from the same plots in 1956.

Acid-soluble (fulvic) fraction of soil organic matter (J. M. Bremner and T. Harada)

Earlier work on the amino-acid composition of the non-dialysable material in the acid-soluble (fulvic) fraction of 0·5*M*-sodium hydroxide and 0·1*M*-sodium pyrophosphate (pH 7·0) extracts of soil was extended. The results obtained confirmed the previous finding that this fraction is similar in amino-acid composition to the acid-insoluble (humic) fraction of soil extracts but contains relatively larger amounts of β-alanine and smaller amounts of the basic amino acids arginine and lysine.

Effect of treating soils with hydrofluoric acid (J. M. Bremner and T. Harada)

An investigation of the use of hydrofluoric acid for the separation of the organic and inorganic fractions of soil showed that pretreatment of mineral soils with hydrofluoric acid or with a mixture of hydrofluoric and hydrochloric acid at room temperature did not increase the amount of organic matter extractable by reagents such as 0·5*M*-sodium hydroxide or neutral 0·1*M*-sodium pyrophosphate. It was found, however, that a considerable amount of soil nitrogen was dissolved by such pretreatment and that a significant fraction of the nitrogen extracted from some mineral soils by *N*-hydrofluoric acid is in the form of ammonia. Attempts are being made to discover if this ammonia is derived from fixed ammonium nitrogen in clay minerals or is formed by hydrolysis of organic nitrogen compounds during the acid treatment. Experiments with vermiculite containing fixed ammonium nitrogen showed that whereas less than half of this nitrogen was released by treatment with *N*-hydrochloric acid, practically all of it was released by *N*-hydrofluoric acid.

Inorganic nitrogen in soils (G. W. Cooke and R. K. Cunningham)

Concentrations of nitrate and ammonium were measured at intervals during the summer both in uncropped soil and under ryegrass in an experiment on Rothamsted clay-loam soil. Levels of nitrate in the top 9 inches of soil remained high on uncropped plots through June and July, which were wet months; heavy and persistent rainfall in August had transported much of the nitrate into the subsoil by the beginning of September. These results were obtained both on unmanured plots and on plots which had received calcium nitrate. On uncropped plots additions of ammonium sulphate gave high concentrations of soil ammonium, which fell slowly during the summer; there was a corresponding rise in nitrate concentrations, but ammonium was converted to nitrate much more slowly than had been anticipated. Plots which were dressed with urea soon gave a high concentration of soil ammonium, which behaved in the same way as ammonium on plots receiving ammonium sulphate. On plots where grass had been sown there was a rapid fall in nitrate concentrations. In early July uncropped soil which

had received either calcium nitrate or ammonium sulphate in April contained about 40 p.p.m. NO_3, whereas corresponding plots on which ryegrass was grown contained less than 10 p.p.m. NO_3. Where ryegrass was grown on plots which had received ammonium sulphate or urea ammonium concentrations fell rapidly and nitrate levels remained very low. On plots which received no ammonium salts or urea, ammonium concentrations remained surprisingly constant at 8–10 p.p.m., both in uncropped soil and under ryegrass. On uncropped plots there had been no loss of inorganic nitrogen from the surface 9 inches at the beginning of August; during the heavy rains of August and early September, nitrate was transported into the subsoil, and there was also a loss of total inorganic nitrogen from the surface 18 inches of soil which may have been due to leaching or to denitrification.

It seems that nitrate is not easily leached out of heavy soils with good structure by average summer rainfall which is sufficient to cause well-marked through drainage. It is possible that nitrate ions are retained inside structural aggregates and that rainfall percolates around the crumbs. Heavier and prolonged rainfall may remove nitrate by causing a deterioration in soil structure. The rapid fall in nitrate concentration under crops or grass which occurs when rapid growth is started must be due to uptake by crops and not to leaching. Quickly-growing grass appears able to remove a large amount of nitrate from the soil in a very short time.

An investigation has been started to develop simple methods of forecasting responses of crops to nitrogen fertilizers by chemical tests on the soils. Under suitable conditions measurements of nitrate concentrations in soil samples taken when field experiments were being laid down indicated whether a response was likely. Attempts are also being made to relate the amounts of inorganic nitrogen released on incubation of soils in the laboratory with the responses of cereals and potatoes to nitrogen fertilizers.

Decomposition of Plant Residues in Grassland Soils

(K. Shaw)

The effects of different conditions and treatments on the rate of decomposition of samples of " mat " (*Rep. Rothamst. exp. Sta. for* **1955**, 52) have been studied by measuring the carbon dioxide and mineral nitrogen produced on incubation at 25° C. for 80 days. Raising the pH of the materials to about 7 by the addition of calcium carbonate or calcium hydroxide increased both carbon dioxide and mineral nitrogen production, the addition of phosphorus as potassium dihydrogen phosphate with calcium carbonate or calcium hydroxide further increased the decomposition of the materials. Little information is available on the field moisture contents of " mats ", but as they appear to be water-saturated for a greater part of the year under field conditions, the effect of different moisture levels on their rate of decomposition was investigated. Maximum carbon dioxide production occurred in the region of the water-holding capacity of the materials, i.e., between 200 and 300 per cent of water. Mineral nitrogen production was not, however, seriously

affected by high moisture levels, which indicates that ammonification of the organic nitrogen is not inhibited under waterlogged conditions. Manganese, boron, molybdenum and copper added to " mat " materials in the presence and absence of calcium hydroxide did not increase the carbon dioxide or mineral nitrogen production under either condition. Since the incubation tests were carried out at 25° C., which is considerably higher than temperatures encountered in the field, the effects of lower temperatures on the rate of decomposition of the " mats " were studied. Experiments are now in progress in which the decomposition is being followed at temperatures between 0° and 25° C. So far, the results obtained show that below 10° C. the rate of decomposition is much less rapid than at 25° C.

This work confirms field experience that liming accelerates decomposition of " mats " formed in grassland. The results also indicate that it would probably be an advantage to apply phosphate in addition to lime to assist breakdown and suggest that the slow rate of decomposition of " mats " is not due to their apparent high water content.

Isotopic Exchange of Phosphorus in Soils and Fertilizers

(O. Talibudeen)

Rothamsted soils

Preliminary calculations suggest that phosphorus on readily accessible soil surfaces can be estimated after isotopic exchange carried out for periods varying from 10 to 20 hours, and that the amounts constitute between 50 and 80 per cent of the total surface phosphorus.

Mono-calcium phosphate was added to the Hoosfield Exhaustion Land and Highfield soils used in previous work (*Rep. Rothamst. exp. Sta. for* **1955**, 48) at the rate of 10 mg. P/100 g. soil, and the soils were sampled at intervals of one, two and three months. The increment in the total surface phosphorus due to added phosphate remained unchanged, 66, 71, 75 and 100 per cent of the added P being recovered respectively on the soils of Hoosfield Plots 1, 3 and 9 and Highfield. In the Hoosfield soils the increment in " readily accessible " phosphorus decreased by an amount equal to 20 per cent of the added P between the first and third sampling. There was no similar change in the Highfield soil, three-quarters of the added phosphorus remaining readily accessible. In the Hoosfield soils, between one-quarter and one-third of the applied phosphorus appears to be inaccessible to the soil solution a month after it has been added. These soils contain about 2 per cent of calcium carbonate; 1 mg. of P added as orthophosphate is converted to a less-accessible form by each gram of $CaCO_3$ during a reaction period of three months.

The possibility of using different media for isotopic exchange work is being explored, and 0·01*M*-$CaCl_2$ and 0·001*M*-KCl have been tried. In soils having a low phosphorus status and containing much $CaCO_3$ it was difficult to determine the low phosphate concentrations in the solutions obtained in this way; much longer times

were needed to attain isotopic equilibrium, and there was little control of pH when low soil : solution ratios were used.

The Highfield soil was progressively leached for increasing times with 0·001*M*-KCl and with 0·001*M*-neutral ammonium citrate in 0·02*M*-KCl. At very slow rates of leaching, when the extracting solution was nearly in equilibrium with the soil phosphate, the rate at which phosphate was extracted was very similar to the rate at which isotopic exchange took place in the equilibrium suspension. The total amount of phosphorus extracted was, however, only 40 per cent of the phosphorus estimated by isotopic exchange.

Rock phosphates

Work previously reported (*Rep. Rothamst. exp. Sta. for* **1953**, 47) was continued, and measurements similar to those made on soils were carried out on rock phosphates in a buffer solution of 0·001*M*-phenyl-barbituric acid at pH 7·5. The phosphorus concentration of the solution at equilibrium was approximately inversely proportional to the amounts of carbonate and fluoride in the samples. Surface areas calculated from the isotopically-exchangeable phosphorus, although following the same trend, were much lower than those obtained by other workers using gas-absorption methods. The data obtained suggest that in samples ground to pass a 100-mesh B.S. sieve (particle diameter 150 μ) the average diameter of the crystallites is of the order 0·5–1 μ.

Soil Potassium

Potassium in crops and soils at Rothamsted and Woburn (R. G. Warren)

Good progress has been made on the analysis for potassium of samples of the leys and arable crops from three ley–arable experiments, two at Rothamsted and one at Woburn. The levels of potassium manuring for some of the treatments in the two Rothamsted experiments, Highfield and Fosters Field, have been inadequate and an acute shortage of soil potassium has developed. The scheme of cropping in these experiments produces a wide range in the amounts of potassium taken up by the different crops and also in the amounts removed from the soil. For cereals the quantities taken up and removed are moderate, but the grass crops grown in one year may contain 200 lb./acre of K. The whole of this amount is removed from the cut grass plots, but on the grazed plots the bulk of it is returned to the land by the sheep. Lucerne also removes large quantities of potassium but less than the cut grass.

Crops grown at Rothamsted frequently give sizeable responses to potassium manuring; at Woburn increases in yield given by potassium are generally much smaller. It appears that the Woburn soil is able to maintain a supply of potassium which, together with normal potassium dressings supplied by fertilizers, is sufficient for arable crops. Analyses now being made of the soils and crops of the Ley–Arable Experiment at Woburn will show whether supplies of soil potassium plus current manuring are quite adequate for the leys and the arable crops which follow.

Potassium in soil extracts (A. W. Taylor)

Studies on the composition of solutions in equilibrium with soils have been applied to the measurement of potassium status. For soils where $a_K/\sqrt{a_{Ca}}$ was low this ratio was found to be constant for electrolyte concentrations ranging from below $0{\cdot}001M$ to above $0{\cdot}1M$. On soils richer in potassium the ratio decreased steadily as the electrolyte concentration was increased.

The work was extended by taking samples of soil from several plots on Sections I, II, III and IV of Broadbalk in autumn 1955. The concentration of potassium ions which must be added to a solution containing a constant concentration of calcium ions ($0{\cdot}01M$) to prevent any exchange when the solution is shaken with a soil sample was determined by trial and error. The values for potassium concentrations in solutions in equilibrium with $0{\cdot}01M$-calcium chloride are set out in Table 4. In Plot 2 (which receives farmyard manure) the equilibrium potassium concentrations fell steadily in years following the fallow period; on other plots the value did not vary regularly according to the time since the section had been fallowed.

TABLE 4

Potassium concentrations in equilibrium with 0·01M-calcium chloride and soil

	Treatment	Equilibrium potassium concentration in the presence of $0{\cdot}01M$-$CaCl_2$ ($[K] \times 10^{-4}M$)
Plot 2	Farmyard manure	25·0
Plot 3	No manure	2·4
Plot 11	Ammonium sulphate, superphosphate	0·8
Plot 12	Ammonium sulphate, superphosphate, sodium sulphate	0·7
Plot 13	Ammonium sulphate, superphosphate, potassium sulphate	11·0

The range of values obtained for equilibrium potassium concentrations is wider than the range obtained by measurements of exchangeable ions, and this method of assessing the potassium status of soils may have practical uses. On theoretical grounds the method is desirable, since it gives a direct measure of the partial molar free energy of exchange of the ions which may prove important in studying potassium " fixation " processes.

MICRONUTRIENTS

Copper deficiency in poplar cuttings (B. Benzian and R. G. Warren)

In 1955 " needle tip-burn " on Sitka spruce seedlings grown at Wareham was shown to be due to copper deficiency. The black discoloration of the leaves of poplar cuttings (*P. robusta H*) grown on the same soil has now been diagnosed as a deficiency of the same micro-nutrient. The symptoms were greatly reduced by a soil application of a fritted trace element material containing Fe, Mn,

Cu, Zn, Mo and B and by foliar sprays of copper applied as a lime–copper sulphate mixture. Table 5 gives scores for blackening, height in inches and copper content of the poplar leaves.

TABLE 5

Effects of copper treatment on poplar cuttings

	Scores for blackening	Height, inches	Cu, p.p.m.
No fritted trace elements	9	20·6	1·3
With fritted trace elements ...	2	29·8	3·1
No Cu foliar spray	8	18·6	1·8
With Cu foliar spray	2	33·1	4·2

Soil manganese (S. G. Heintze)

The effects of long-continued fertilizer treatments on some fractions of soil managanese were studied by estimating the exchangeable, readily-reducible and pyrophosphate-soluble manganese in selected plots of the Rothamsted Experiments. The small exchangeable manganese fraction varied with soil pH, and there were no effects from fertilizer treatments. From 5 to 75 per cent of the total manganese was in a readily-reducible form, and there were only small seasonal variations. Where farmyard manure had been applied both on arable and grassland the readily-reducible manganese was decreased. Ammonium sulphate or rape-cake, which both reduced soil pH, had no effect on this fraction on those plots which did not receive minerals or which received farmyard manure. Where full mineral fertilizer dressings were given, long-continued application of ammonium sulphate increased readily-reducible manganese on the arable land of Barnfield and Long Hoos, but the same treatment applied to both limed and unlimed plots of the Park Grass Experiment caused a large reduction. This fraction of soil manganese also decreased where legumes had been grown.

The quantity of manganese dissolved by brief extraction with pyrophosphate was much less than the readily-reducible fraction. Ammonium sulphate or mineral fertilizers had only small effects on pyrophosphate-soluble manganese; there was some increase in this fraction where farmyard manure had been applied except in the Park Grass Experiment. Previous cropping with legumes increased pyrophosphate-soluble manganese. Some preliminary work was done on redox levels of soils. Soils containing sufficient available manganese had higher redox levels than comparable soils where manganese deficiency occurred in crops.

ANALYTICAL

Fluorine (A. C. D. Newman)

In extending previous work on the solubility of rock phosphate it became necessary to develop a reliable method for determining small quantities of fluorine. The effects of fluoride on the colours produced by the reactions of a variety of organic compounds with aluminium salts were examined. Quinalizarin sodium sulphonate was finally chosen. A solution of the reagent in water, buffered to

pH 3·9 and treated with an equal volume of 0·0005*M*-aluminium potassium sulphate, produced a stable coloured solution. The reduction in the colour of this reagent caused by addition of fluoride solutions was measured photo-electrically, and good agreement was obtained with solutions standardized by the macro-method involving precipitation as lead chlorofluoride. The effects of elements which interfere with the reaction were examined. Metals which interfere (aluminium, ferric iron, thorium, beryllium, titanium and zirconium) may be removed from solution by a cation ionic-exchange resin. High concentrations of phosphate (relative to fluoride) also interfere. When appreciable quantities of phosphate were present, they were separated from fluoride using an anion-exchange resin. Quantitative recovery of fluoride from solutions containing several times as much phosphate was achieved. The comparative insensitivity of the method to small quantities of phosphate, together with the ease with which large amounts of phosphate may be removed by ion exchange, makes the method promising for determining fluorine in solutions derived from rock phosphate.

PEDOLOGY DEPARTMENT

A. Muir

A. Muir and C. Bloomfield attended the 6th International Congress of Soil Science, the former being chairman of Commission V (Genesis and Cartography of Soils). During Hilary Term A. Muir gave a course of lectures on tropical soils in the Forestry Department, University of Oxford. I. Stephen has taken up a temporary post at the University of Illinois. R. R. Storrier, from Sydney, Australia, will carry out laboratory studies on the soils he has been mapping in conjunction with the Soil Survey.

Mineralogy

Weathering and soil development of igneous rocks in Shropshire

Work on this subject has been concentrated into two main lines: (1) a detailed investigation into the products of weathering of picrite (an olivine-rich rock), and (2) a study of the development sequence of soil types found on the igneous rocks.

(1) *Picrite weathering*

In last year's Annual Report mention was made of a material which appeared to belong to the montmorillonite group which gave an excellent fibre pattern. This has led us to examine other materials in the hope that we might obtain a three-dimensionally ordered mineral of this group. A material from the same source has been found which, at least in part, consists of a montmorillonite-type mineral and which shows a degree of three-dimensional order. This new material was reminiscent of the material which has been called iddingsite, and a sample of this material is being examined. The aim of these studies is to obtain material from which X-ray-diffraction data more akin to single-crystal data can be obtained. This would allow the investigation of this mineral and many of its properties by single-crystal methods which are immensely more powerful than the powder-diffraction methods which have been used so far.

Brief notes on the preliminary examination of some of these materials are given below.

(a) *Fibro-lamellar aggregates.* In the basal soil layer fibres and lath-shaped grains of fibro-lamellar character, light yellowish-brown in colour, are fairly abundant. They appear to be derived by weathering from veins of cross-fibre greenish "serpentine" which traverses the picrite. This "serpentine mineral" has been shown by X-ray analysis to possess a chlorite-type structure.

The fibrous aggregates give fibre patterns with sharp reflexions, the repeat distance along the fibre axis is 5·3 Å. A large number of these fibres have been cursorily examined, and the variations in the diffraction patterns can be attributed to changes in humidity. The complex frequently found at normal humidities has a basal spacing

of 15 Å. The zero-layer of the fibre pattern of this complex has been indexed out to a spacing of $d = 1{\cdot}45$ Å. The reflexions can all be indexed on the basis of an orthogonal net with $b = 9{\cdot}22$ Å., $c = 15{\cdot}07$ Å. In all, twenty-nine reflexions have been indexed, fourteen without ambiguity. Five unambiguously indexed reflexions are *Okl* type. Reflexions with k odd appear to be absent. The fibre beginning from a long spacing of 15 Å. can be contracted to 10 Å. by heating treatment and re-expanded again to 15 Å. by rehydration and further expanded to 18 Å. by glycerol. Throughout these changes a good fibre pattern is maintained. The fibre pattern does not change in gross features with change of long spacing, but the finer details of the pattern are altered. This may be of assistance in determining the crystal structure of the materials by allowing the use of methods similar to those used by Boyes-Watson, Davidson and Perutz (*Proc. Roy. Soc.* 1947, **A.191**, 83) in the study of the structure of horse methaemoglobin.

(b) *Lamellar montmorillonite mineral.* The X-ray characteristics and optical properties of this mineral have been established. The flakes are brown in colour with *Bxa* $\perp$ 001, the plane of well-developed cleavage. A description by Arnold-Bemrose (1894, *Quart J. geol. Soc. Lond.* **50**, 63) of pseudomorphs after olivine (" Potluck pseudomorphs ") in the Carboniferous tuffs and dolerites of Derbyshire suggests their close identity with this mineral, the pseudomorphs being brown in colour and readily cleavable, the cleavage flakes showing a biaxial negative interference figure. Specimens of the " Potluck pseudomorphs " have been obtained for comparative study. An investigation of " iddingsite ", the name commonly applied to the lamellar deep reddish-brown to ruby red alteration product of olivine, has also been started in connection with the present study.

This material occurs as brown lamellae with optical properties which suggest three-dimensional order. At least part of the material in an optically continuous specimen belongs to the montmorillonite group, for a basal spacing of about 15 Å. can be increased to about 18 Å. when treated with glycerol. Oscillation photographs about the normal to the optic axial plane show a pattern of spots superposed on powder rings, and from the spots an axial repeat distance of 9·2 Å. is obtained. In a perpendicular direction in the plane of the flake the repeat distance is 5·3 Å. The nature of the spots and rings suggests that we are dealing with a disordered crystal along with a microcrystalline substance which shows preferred orientation with respect to the crystal. A more detailed examination will be required to find out if the crystal and the powder are the same material in different forms or if one material, e.g., the powder, is derived from the other, i.e., the crystal, by alteration processes.

(c) *Iddingsite.* A specimen of iddingsite selected from its optical properties has been examined by oscillation methods. The specimen was set to rotate about the normal to the optic axial plane. These photographs show definite layer lines of rather diffuse spots. The identity period is 10·1 Å. for strong layer lines, but weak intermediate layer lines show that the true repeat distance is 20·2 Å. Also on the photograph is a layer line with a period of 5·3 Å., which may represent the parallel growth of a material similar to the

lamellar material mentioned above. This specimen is now being examined by moving-film methods. It appears from this specimen that a diffraction pattern distinct from olivine and from montmorillonite-type minerals is obtained from at least one specimen which would be called iddingsite. (G. Brown and I. Stephen.)

(2) It has proved possible to recognize a development sequence of soils in Llanfawr, a small ridge of augite–andesite rising to about 1,325 ft. The first member of the sequence is represented by a protoranker (an AC-soil) developed under moss and bilberry found on the highest, most exposed part of the ridge where rock outcrops. Lower down the slopes transition stages between rankers and braunerde-like soils are developed, and the final stage is that of a typical braunerde showing A, (B) and C horizons. Similar development sequences have also been noted on other outcrops of igneous rocks in Shropshire, and on the " Ivyscar-rock " (a quartz microdiorite) on the Malvern Hills, and details of the transition are being investigated. (I. Stephen and D. A. Osmond.)

(3) *Chiltern soils*

Mineralogical investigations of the fine sands and coarse silts of three profiles, representative of the Winchester, Batcombe and Charity series, as mapped by the Soil Survey, have been completed.

The " heavy mineral " studies indicate non-uniformity of parent material in the Batcombe, and, to a smaller degree, in the Winchester profile. In the Batcombe (excluding the A horizons) and in the Winchester, the main non-opaque heavy minerals are zircon, tourmaline, rutile, staurolite and kyanite, with garnet and green hornblende rare. The evidence for non-uniformity of parent material is strongest in the Batcombe, and is based on the fact that in the A horizons, garnet, and to a lesser extent, epidote and chlorite are conspicuous heavy minerals, while in the lower layers they are present only in minor amounts. The same trend is shown in the A_1 horizon of the Winchester profile. In the Charity profile there is no mineralogical evidence for profile non-uniformity, and garnet is a common constituent of the residues in all horizons. The association of the garnet–epidote–chlorite assemblage with the horizons rich in coarse silt suggests that these deposits may be of loessial origin.

Quartz is the dominant " light mineral " throughout the Batcombe and Charity profiles, and in the upper 2 feet of the Winchester, but in the lower layers of the latter profile the dominance of flint and the presence of collophane supports the view that these basal layers are largely Chalk-derived. (I. Stephen.)

Silica. Unusual forms of chalcedonic silica occur in the sand fractions of clay-with-flints soils. Three types of grain have been recognized: those which consist of bundles of parallel rods, those which have a honeycomb appearance and more rarely botryoidal grains. Optical examination showed that the grains consist of chalcedonic silica. X-ray examination of powders showed the quartz pattern. Oscillation photographs of single rods and cell walls show that the quartz crystallites are arranged with their *c*-axes in sub-parallel alignment perpendicular to the rod axis. There is also a strong tendency for the *a*-axes to lie along the rod axis.

Optical examination of single rods and thin sections of grains cut in different directions confirm these findings and also show that the grains are often optically continuous over considerable areas. Chemical analysis of air-dry material gave SiO_2 99·16 per cent, H_2O 0·84 per cent. The fragile nature of the grains shows that they have been formed more or less *in situ*. The grains are thought to be of inorganic origin, and a possible mode of formation has been proposed. This work is now being prepared for publication. (G. Brown and C. D. Ollier.)

Clay Mineralogy

(a) *Limestone residues.* This work extends the work on Chalk residues mentioned in last year's report. This year samples from Lower Chalk, Oolitic Limestone, Magnesian Limestone and Carboniferous Limestone have been examined.

(b) *Aylesbury Sheet* (*238*). In connection with the soil survey of this sheet a large number of soil clays and clays from the underlying geological formations have been examined. Fifty samples from Gault Clay, Upper Greensand, Chalk Marl, Lower Chalk and Kimmeridge Clay have now been studied. In addition, the clays from twenty-three complete soil profiles have also been examined from soils occurring in the area. (R. Farrow and A. M. Du Feu.)

Quantitative analysis

Iron oxides. The work mentioned in last year's report has been continued. Co-precipitated iron oxides on kaolinite give broad haematite reflexions when heated at 700° C., and this results in low values for Fe_2O_3 when the estimations are based on standard curves obtained using well-crystallized haematite and peak intensities. Attempts to use integrated intensities measured photographically have failed due to the experimental difficulty in measuring peak areas accurately enough.

It has been found that the breadth of haematite reflexions obtained from co-precipitated iron oxide on kaolinite is related to the proportion of iron oxide present in the mixture. This suggests that the iron oxide in contact with the clay mineral surface forms smaller haematite crystals than the iron oxide which is further from the clay surface. This in turn suggests that a proportion of the iron oxide is more strongly held on the surface of the clay. It may therefore be possible to investigate the active surface of clay minerals for sorption of iron oxide by X-ray methods when suitable methods are used for the quantitative analysis of the haematite formed on heating. It is hoped that the X-ray diffractometer will assist in this work by giving accurate estimations of integrated intensities, as well as peak heights of haematite reflexions from well-crystallized (" standard ") haematite and also from the less well-crystallized haematite obtained when co-precipitated iron oxide is heated. (R. Farrow and G. Brown.)

X-ray structure analysis

The 1953 Annual Report mentioned the need for faster methods of performing crystallographic calculations and described the work

being done on an electromagnetic Fourier synthesis machine of the Bevers–McEwan type. The presence of the Elliott 401 electronic computer at Rothamsted has made much faster calculation possible. In collaboration with J. C. Gower of the Statistics Department, programmes have been written for the calculation of structure factors and two-dimensional Fourier syntheses. For a structure with N atoms in each unit cell a structure factor can be calculated in $7N/80 + 3$ seconds, which shows the speed achieved. (J. H. Rayner.)

Electron microscopy of montmorillonite minerals

We have been co-operating this year with H. L. Nixon in studying the morphology of montmorillonite minerals, and the results obtained have shown a considerable improvement on previously published work.

The mineral investigated most fully is the Unter-Rupsroth montmorillonite from the Rhon-gebirge, Germany. When sodium- or lithium-saturated samples of this mineral are completely dispersed in water they show a flat lath or plate-shaped habit. The particle size is large for a montmorillonite, dimensions of 3×4 μ being quite common. Sections of the plate edges are frequently straight and joined by steps at angles of 120° to the edges. It is unusual to find a complete hexagonal plate, as in the kaolin minerals, but these small 120°-angle steps are common and reflect the pseudo-hexagonal symmetry of the mica layer in the same way.

The plates or laths are extremely thin, and estimates of the thickness are liable to be inaccurate owing to the low shadowing angle and thickness of metal that have to be employed. However, it seems fairly certain that a completely dispersed montmorillonite has a flake thickness of 10 Å. or one mica layer.

Wyoming bentonite has also been investigated. The flakes are mostly plate-shaped with irregular outlines, although one or two with crystallographic regularity have been seen. The range of particle size in the latter and in the montmorillonite from Redhill, Surrey, is very considerable, and it is hoped to make an estimate of this by comparison of micrographs and settling velocities when a suitable centrifuge is available.

Preliminary attempts to use the spray-droplet technique with montmorillonite suspensions were successful and showed that some droplets contained only a single flake 10 Å. thick. The droplets had to be sprayed without albumen on account of the thinness of the sheets, so that unfortunately the droplet outline could not be seen and had to be inferred. It is hoped to continue this work in the future, and put the results on a quantitative basis.

Black Jack Mine Beidellite

A full investigation of the nature and properties of the mineral has been undertaken. It is found as a gangue with lead and silver ores, and is particularly pure, with minor amounts of quartz as the only recognized impurity.

The naturally occurring mineral contains 73 m. eq. Ca, 25 Mg, 2 Na and 2 K per 100 g., as exchangeable cations, and yet only

0·16 per cent MgO enters the lattice in the octahedral positions. 0·3–0·4 per cent K_2O is not exchangeable, and the Fe_2O_3 content is 0·5–0·7 per cent. X-ray powder patterns give typical 17·7 Å. (001) series and (*hk*) bands with glycerol-treated flakes.

Preliminary electron micrographs show very large lath-shaped flakes, 25 μ long, 8 μ broad and 40–50 Å. thick in one instance (fine sand in one direction, silt in another and very small clay in the third!). The particles have good crystallographic outlines, and frequently successive laths are superposed with parallel or slightly fanned edges.

Comparison of the derivative of the thermal-balance curve and the d.t.a. trace shows close similarity. The Ca-clay shows the typical two-component low-temperature exothermic peak corresponding to loss of hygroscopic moisture, and calculation of the water associated with the high-temperature component of this peak gives 3·5 per cent water, or slightly more if the asymmetry of the peak is allowed for. This is considerably less than the 5·4 per cent required if each Ca ion is to be 6 co-ordinated with water molecules.

There is a loss of water, forming a small peak and not exceeding 1 per cent between 290° and 400° C. This may be due to an impurity, and needs further investigation. The total loss of structural water occurs between 200° and 900° C., and is equal to 7·2 per cent. (A. H. Weir.)

Apparatus

A microfocus four-window X-ray tube of the Ehrenberg–Spear type has been constructed and has been in use for about six months. The size and shape of the focal spot can be varied within wide limits. A point focus of about 40 μ diameter can be obtained for applications requiring a fine focus. For routine diffraction studies a focal spot 1 × 0·1 mm. is used. Other sizes and shapes of focal spots can be obtained if required. (G. C. Dibley.)

Micropedology

Work has continued on the morphology of soils and sediments (mainly from Cyprus and the Chiltern area) by means of the thin-section technique.

Chiltern soils

Excellent samples of highly oriented clay layers have been noted where a clay drift overlies " brickearth ". The latter is seamed with narrow more or less vertical fissures, several feet long, practically filled with red-brown clay that contrasts strongly with the yellow-brown brickearth. The clay deposit is often layered, and optical examination of sections cut normal to the layering shows mass extinction and positive elongation, indicating a high degree of optical continuity. The layered nature of the clay aggregates in the joints suggests that they are derived from the overlying clay drift by a process of repeated cyclic sedimentation.

Thin-section studies of horizons of the Batcombe and Charity profiles suggests that clay migration has been an operative process in the development of at least a part of the profiles. This work is

being continued, and it is hoped that a study of the distinctive patterns of clay morphology that exist in soils will yield information about the conditions of deposition of the parent material, and the genesis and development of the soils themselves.

Cyprus soils

The micromorphology and mineralogy of terra rossas and rotlehms associated with calcareous sediments and igneous rocks respectively have been studied. The investigation confirms differences observed in the field, and assists in the differentiation and classification of the soils. A report on this work has been submitted for publication. (I. Stephen and D. A. Osmond.)

Physical Chemistry of Soil Minerals

The mechanism of aggregate formation in soils

A calorimetric method has been devised for determining the area of the liquid–vapour interface in systems of solid particles wetted with a liquid. A theoretical relation between this area and the suction applied to the liquid has been derived and is being experimentally verified. By the use of this method it is possible to obtain new information concerning the plastic changes which occur as solids wet and the effect that the solid has on the surface energy of the liquid film. It is anticipated that in conjunction with the low-temperature, gas-adsorption methods in use the process of aggregate formation in soils can be followed and methods of control investigated. (R. Greene-Kelly and R. C. Gallavan.)

Heats of wetting of soils

Whilst the total heat of wetting of a soil is dependent on the clay content, the heat of wetting per unit area of wettable surface is markedly dependent on the work of structural adjustment necessary to accommodate the water film. It has been found that for soils a convenient measure of the exchangeable cation environment may be made by measuring the heat of wetting per milli-equivalent of exchangeable cations. The results have suggested that most exchangeable cations in soils (low in organic matter and iron oxides) originate from sterically restricted positions probably located inside the clay mineral crystals. The only exceptions so far found are soils very high in kaolins. It seems that the ionic environment of exchangeable cations in illites is fundamentally identical to that in montmorillonites and vermiculites, in that the ions originate from deep in the crystals and not merely from their frayed edges. Further investigations on illites and vermiculites, with special reference to potassium fixation, are planned. (R. Greene-Kelly.)

Iron oxides

It has been observed that ferruginous soils give exothermic peaks during differential thermal analysis. Although this has been attributed to iron oxides, the reason for the effect is not known. By a combination of differential thermal analysis, weight loss analysis and X-ray methods it has been established that goethites of increas-

ing particle size show a diminished exothermic peak and a progressive difference in temperature at which adsorbed and structural water are lost. The final product is always haematite of relatively large crystal size, and it seems likely therefore that the exothermic reaction is due to the difference in total surface energy between goethite and its firing product. If the crystallization of the haematite is inhibited, for example, by epitaxial growth of the iron oxide on kaolinite, then the exothermic peak is greatly reduced. (R. Greene-Kelly and J. B. McGarry.)

Water adsorption by clay minerals

Fundamental studies on water adsorption by members of the montmorillonite group have been continued. Much new data have been accumulated; for example, it has been shown that little or no difference in the water-sorption characteristics was found between members of the group provided the charge density remained constant, although the regularity of the hydrated crystal varied considerably. This would suggest that the way the sheet charge is generated in the montmorillonite group is of little importance in determining the water-film thickness, and hence the ionic mobility in the crystals. (R. Greene-Kelly.)

Potassium fixation and crystal energy

There have been two suggestions to explain why potassium ions are fixed by clay minerals. The first is that the potassium ion is of such a size that it satisfies special co-ordination requirements and the second that the ionic mobility is a function only of the hydration possible in the crystal, and this in turn depends on the hydration energy of the interlamellar cations and their charge density. An attempt is being made to decide between these two factors by the direct measurement of the crystal-energy changes due to various interlamellar cations. This is being accomplished by the accurate determination of the heats of solution, and so far the results suggest that the crystal energy is little affected by the presence of potassium ions. This would be in accord with the hydration theory of potassium fixation. Heats of solution measurements are also being applied to quantitative investigation of the energy associated with "mistakes" in clay minerals, and thus supplement the qualitative results from X-ray analysis. (R. Greene-Kelly.)

Miscellaneous investigations

Differential thermal and weight-loss analyses and determination of surface areas by the use of nitrogen or carbon dioxide adsorption at low temperatures have been carried out on a variety of materials in connection with other studies. In addition, an investigation of the surface energy of quartz powders as a function of particle size has been carried out for the Ministry of Fuel and Power (Safety in Mines) in conjunction with studies on the origin of pneumonokoniosis. (R. Greene-Kelly, R. C. Gallavan and J. B. McGarry.)

The laboratory synthesis of clay minerals

A programme of laboratory synthesis of clay minerals has been begun in an effort to provide fundamental information on the formation of clay minerals in soils.

At pressures and temperatures well above those found in soils (say at 300° C. and 300 atmospheres) clay minerals can be synthesized in a few hours from silica–alumina gels. A number of syntheses of this kind have been carried out using apparatus kindly put at our disposal by the I.C.I. Plastics Division at Welwyn Garden City. The products have been characterized by methods already developed in this department. X-ray diffraction and differential thermal analysis show that a substantial part of the gel has been converted to clay minerals. Both kaolin and beidellite have been found. X-ray diffraction showed that the kaolin mineral was kaolinite rather than halloysite. The d.t.a. curves showed marked asymmetry in the kaolinite peaks at 540–590° C. This shape of peak has been associated with halloysite in contrast with the symmetrical peak usually found for kaolinite. In this case it is most probably due to the fine particle size of kaolin. This is also suggested by an electron-microscope examination of one of the samples.

These high-temperature experiments will now be continued at Rothamsted, and a high-pressure laboratory is being set up. The apparatus should make possible measurement of the kinetics of clay mineral formation. The change of ion-exchange properties accompanying it will also be followed. The apparatus may later be used to study clay mineral formation by breakdown of crystalline alumino-silicates—probably the main source of clay-mineral deposits in nature.

Attempts to prepare clay minerals at temperatures closer to those found in soils have not so far been successful. X-ray and d.t.a. examination of silica–alumina gel samples boiled for a month at ordinary pressure show some changes from the unboiled material, but no well-crystallized clay minerals. For comparison, experiments using much more dilute solutions such as were used by Hénin (e.g., Hénin and Robichet, *Clay Minerals Bulletin* **2**, 110 (1954)), will be tried. (J. H. Rayner.)

Spectrochemistry

Further work has been done on the study of trace-element distribution in Lower Lias shales, the parent materials of the teart soils of Somerset. A point of particular interest is the apparent rarity of this trouble on soils derived from similar bituminous shales. This raises the question as to whether the high concentrations of molybdenum which give rise to teart are in fact very rare or whether it is due to an unusual combination of predisposing factors of which a high level of soil molybdenum is only one.

Similar trouble due to molybdenum/copper unbalance has been reported from New Zealand, California, Eire and elsewhere, but in none of these cases has it been shown to be due to high concentrations of molybdenum in the parent rock. In this connection it has been found that the relatively small amount of copper in the Lias

shales (<100 p.p.m.) is much more firmly bound than is the molybdenum. Prolonged leaching of the shale with water was found to remove about half of the molybdenum. Treatment with an HF/HCl mixture removed most of it, leaving only a small residue attributable to the pyrite incorporated in the shale. These treatments removed very little of the copper and suggest that it is mostly organically bound, since little occurred in the pyrite.

When such a material, containing also calcium carbonate, is subjected to soil-forming processes, it is to be expected that most of the molybdenum will become soluble and be slowly removed from the soil at a rate dependent upon the drainage conditions. The copper, being more firmly bound, is largely unavailable, and therefore unable to counteract the toxic effects of the molybdenum.

As previously reported, a relationship has been found between the amounts of molybdenum, vanadium, copper and nickel in these shales, which suggests a common cause for their accumulation, such as adsorption by organic matter. It is well known that vanadium is accumulated by certain marine creatures and that it is sometimes heavily concentrated in oils; but the other elements mentioned are not known to be appreciably accumulated in this manner, which suggests that this mechanism is probably not a major factor in the Lias shales.

It seems likely that such high concentrations of molybdenum are not necessarily rare, but in order to produce teart soil several other factors are involved, e.g., presence of calcium carbonate, relatively low or unavailable copper and imperfect drainage. (H. H. Le Riche.)

Soil Chemistry

It was reported last year (*Rep. Rothamst. exp. Sta. for* **1955**, 65) that the solution of ferric oxide by aqueous leaf extracts appears to be largely the result of the joint action of carboxylic acids and reducing compounds. It now seems that the reducing compounds involved are polyphenols. After having been stored for some time, a rimu leaf sample was found to have lost the greater part of its ability to dissolve ferric oxide. A comparison of this material with an active sample has been undertaken, as this seems to be a promising approach to the problem of classifying the constituents responsible for the action of the leaf extracts.

Qualitative tests with triphenyltetrazolium chloride showed that a water extract of the active leaf had a much greater reducing capacity than a similar extract prepared from the inactive sample, and the difference could not be ascribed to differences in the reducing sugar contents of the two samples. Although the satisfactory use of triphenyltetrazolium chloride has been reported for the determination of reducing sugars, it has not been possible to use this reagent for a quantitative determination of reducing capacities of aqueous leaf extracts. However, by means of hypoiodite oxidation before and after clearing with lead acetate, it was found that the non-sugar-reducing capacity of the active rimu was some three times greater than that of the inactive material. The greater extent of oxygen absorption by an extract of the active leaves under alkaline

conditions was an indication that the reducing compounds responsible for the difference are polyphenols.

Polyphenols have been separated by precipitation with chloroform from methanol extracts of the leaves after prior extraction of the latter with light petroleum ether. Ultra-violet absorption spectroscopy of the chloroform precipitates obtained from the two rimu samples indicates that the polyphenol content of the active leaf, in agreement with the reducing capacity determination, is approximately three times as large as that of the inactive rimu.

Some difficulty has been experienced in securing complete removal of carboxylic acids from the chloroform precipitated polyphenols, but nevertheless it has been found that for the active rimu, while neither the polyphenols nor the acids alone have very much action on ferric oxide, the two together give a solution/reduction effect that approaches that of the untreated extract in magnitude. Further, addition of polyphenols from the active rimu to a water extract of the inactive leaves leads to a very considerable increase in the extent of solution of ferric oxide, the increase being greater than would be expected if the effect were purely additive.

In view of the history of the inactive rimu it seems probable that its deterioration resulted from an insufficiently rigorous initial drying, so that enzymic oxidation of the polyphenols took place, probably following the absorption of atmospheric moisture. The effects of such enzymic action on the properties of leaf extracts is therefore being studied.

It seems probable that the acid constituent of aspen-leaf extracts, to which reference was made in connection with the deflocculation of kaolinite (*Rep. Rothamst. exp. Sta. for* **1955**, 65), is a polyphenol oxidation product. While both this substance and the polysaccharide constituent alone cause deflocculation of kaolinite, at moderate concentrations the two together give appreciable reflocculation of the clay. (C. Bloomfield.)

SOIL MICROBIOLOGY DEPARTMENT

H. G. Thornton

P. S. Nutman returned on 2 July from Canberra, Australia, where he had spent three years on secondment to the Division of Plant Industry, Commonwealth Scientific and Industrial Research Organization, Canberra.

Mr. R. M. Jackson, Lecturer in Plant Pathology, University College, Ibadan, Nigeria, joined the scientific staff of the Department on 1 January 1956.

Mr. Allan Gibson, from the Division of Plant Industry, C.S.I.R.O., Canberra, Australia, arrived on 16 August 1956 to do research on problems connected with nodule bacteria and legumes.

Mr. J. Steffens, from Berlin University, was here from 5 April till 14 August 1956 helping Norman Walker in the synthesis of aromatic compounds needed in the latter's work.

Mr. Iver Berlier, from Abidjan, French West Africa, was here from 17 September till 26 October 1956.

Recent developments in soil microbiology, together with the work of plant pathologists concerning root disease organisms, emphasizes the urgent need for more information on the ecological factors in soil that encourage or control the growth of specific groups of micro-organisms therein. For this reason a considerable part of the Department's work has dealt with subjects related to this general problem.

The Fungistatic Action of Fresh Soil

There is increasing evidence that some of the antibiotics produced by specific organisms are active in soil, but there is also evidence that the fresh soil contains a substance or substances destroyed by heating that inhibit the germination of spores of a number of fungi introduced into the soil. The origin of this fungistasis is not yet known, but it is likely to be a factor of importance in its effect on plant-disease fungi, as well as on the balance of the micropopulation as a whole. R. M. Jackson has found that soils from differently manured plots on Broadbalk differ in the degree to which they inhibit germination of *Penicillium* conidia. Species of soil fungi also show very different degrees of sensitivity to this fungistasis. A range of fungi having varied sensitivities to Broadbalk soil showed the same relative sensitivities in six out of seven soils of widely different characters, but behaved differently in one very acid soil. The fungistatic action of soil may be overcome or reduced by the presence of certain sugars, and in some cases by the near presence of plant roots. These effects are being further investigated.

The Establishment of Organisms in Partially Sterilized Soil

The possibility of controlling root-disease organisms by introducing antagonists into the soil depends in part on whether such antagonists can be successfully established in soil when introduced therein. We know very little about the soil conditions or about the qualities in the organisms themselves that are necessary for successful establishment. It is well known, however, that some organisms spread rapidly through partially sterilized soil, perhaps because of the reduced competition with the soil population. Margaret Brown has carried out experiments with three micro-organisms each introduced into soil that has been steamed for 1 hour. The fate of the introduced organism was followed in each case by platings at regular intervals.

The first organism, *Azotobacter chroococcum*, disappeared from the soil in 31 days. The second, *Chromobacterium prodigiosum*, was successfully established, possibly assisted by the production of an antibiotic. The third organism, a Nocardia, was successfully established both in Rothamsted and in Woburn soil, in both of which it showed fluctuations in the plate count apparently related to repeated changes from mycelial to rod stage, and *vice versa*.

The Micropopulation of the Root Surroundings

The types of fungi that predominate on the root surface, in the immediately adjacent soil (rhizosphere) and in soil at a distance from the root (non-rhizosphere soil) have been further surveyed by E. A. Peterson. He has grown wheat and clover in two different soils and examined samples at intervals from the date of sowing. Similar results were obtained in both soils. More fungi were found in the rhizosphere than in non-rhizosphere soil, the disparity increasing with the age of the plants. Different fungi became predominant in the rhizosphere at different ages of the plant.

The root surface carried a quite distinct fungal population, in which Fusarium and a sterile mycelium were very predominant.

The types of fungi found in healthy Woburn soil and in soil rendered " clover sick " in the pot experiments of H. H. Mann and T. W. Barnes were also examined. A comparison was also made of the microflora of the rhizospheres of clover plants grown in " sick " and in healthy soil respectively. Some fungi were found to be relatively more abundant in the " sick " soil or rhizosphere, and these were tested for pathogenicity to clover growing in pots of healthy Woburn soil. None of them harmfully affected the clover growth. Sick clover plants recovered when transplanted into healthy Woburn soil. This result, together with the finding that clover grew normally in " sick " soil to which 10 per cent finely divided animal charcoal had been added, suggests the action of some toxic substances, although so far attempts to extract any such substance from sick soil have been unsuccessful. The remedial effects of charcoal were previously noticed by Mann and Barnes.

Platings of rhizosphere soil made by Margaret Brown and E. A. Peterson on media containing antibiotics have revealed the existence

therein of bacteria resistant to streptomycin and to chloromycetin. Streptomycin-resistant organisms have been found to be much more abundant in rhizosphere than in non-rhizosphere soil, particularly with older plants and those growing in clover-sick soil. Aureomycin added to the plating medium effectively controlled bacterial growth without apparent effect on the development of fungal colonies.

The Microflora of Soils after Treatment with Trichloracetic Acid

Jane Meiklejohn and R. M. Jackson examined the microflora from two of the plots on Stackyard Field at Woburn three weeks after treatment with Trichloracetic at 20 lb./acre, and compared the result with those from untreated soil from the same plots. Microscopic counts of soil bacteria, plate counts of bacteria, actinomycetes and fungi, and tests for the presence of nitrifying and nitrogen-fixing organisms showed no significant differences between treated and the corresponding untreated soil.

Decomposition of Halogenated Phenoxyacetic Acids by Soil Bacteria

The metabolism of 2 : 4-dichlorophenoxyacetic acid (2 : 4D) and of 4-chloro-2-methylphenoxyacetic acid (MCPA) by a strain of *Flavobacterium peregrinum* and by an Achromobacter species has been studied by N. Walker and T. I. Steenson. It was found that cells from young cultures were more active than those from older cultures in oxidizing these substrates. Using such young cells, evidence from manometric experiments indicates that one or other of these organisms dissimilate 2 : 4-D through 2 : 4-dichlorophenol and 4-chlorocatechol, and MCPA through 5-chloro-2-cresol. Cells adapted to 2 : 4-D would also oxidize 2 : 4-dibromo- and 4-bromo-2-chlorophenoxyacetic acids and their corresponding phenols, but would not oxidize any of the isomeric dichlorophenoxyacetic acids except 2 : 4-D. Mr. J. Steffens assisted in the synthesis of a number of aromatic compounds required in this work.

The Numbers of Azotobacter Cells in Broadbalk Soils

The Broadbalk plots, with their fallowed and cropped sections, afford an unusually good opportunity to survey non-symbiotic nitrogen-fixing organisms and to relate their numbers to crop yield.

Jane Meiklejohn has continued a survey of the estimated numbers of Azotobacter in eight of the Broadbalk plots sampled at intervals, on each occasion including fallow sections and those carrying the fourth successive crop. The estimated numbers of Azotobacter cells was found to be very small, seldom exceeding 1,000 per gram of soil. In all comparisons between plots with and without nitrogen dressings, the latter gave the higher numbers of Azotobacter cells. Thus Plot 3 gave higher numbers than Plot 10, Plot 5 than Plot 7, and Plot 18 than Plot 17, which received a nitrogen dressing this season. Plot 13, which receives potash as well as nitrogen and

phosphate, gave consistently higher Azotobacter numbers than Plot 11, which has nitrogen and phosphate but no potash.

Other Nitrogen-fixing Organisms

The small numbers of Azotobacter in our soils suggests a search for other non-symbiotic nitrogen-fixing organisms. From soil platings in a nitrogen deficient medium Margaret Brown has isolated several organisms other than Azotobacter that seem able to fix small amounts of nitrogen. The most efficient of these is a black fungus that fixed 4–5 mg. of nitrogen per g. of glucose oxidized.

The Anaerobic Decomposition of Cellulose

Reducing processes in the soil may be of great importance, e.g., in nitrogen fixation and in the reduction of insoluble oxides. In the supply of energy for these processes the anaerobic decomposition of cellulose may be expected to be of first importance. But we have insufficient knowledge about the bacteriology or biochemistry of this breakdown. This is largely due to the difficulty of isolating the organisms. F. A. Skinner has begun an investigation on the isolation and activities of these anaerobic cellulose bacteria. In cellulose–agar cultures derived from a soil-enrichment culture, two types of cellulose-attacking colonies were found: (1) punctiform colonies, which were usually embedded in the medium, and (2) thin surface colonies, whose margins extended rapidly to form large actively cellulolytic areas. Both types of colony consisted of spore-forming, rod-shaped bacteria. Surface growth has been found to be contaminated with other types of spore-forming bacteria very similar in appearance to the cellulose decomposers. These contaminants are being studied, as they may well have a marked stimulatory action on cellulose decomposition. A feature of particular interest shown by the cellulose–agar cultures is the extremely long period which intervenes between inoculation and the development of recognizable cellulose-decomposing colonies. A delay of two weeks is common, and on one occasion a delay of seven weeks was recorded.

Growth of the cellulose-decomposing bacteria has not taken place in any medium with an oxidation–reduction potential more positive than about —30 mV.

One difficulty encountered in the preparation of cellulose–agar medium is that of keeping the finely-divided cellulose in suspension until the molten agar sets. The cellulose flocculates rapidly in the presence of electrolytes, which are essential ingredients of the media. This flocculation has been prevented by the inclusion of quite low concentrations of the water-soluble sodium carboxymethyl-cellulose.

The Infection of the Clover Root by Nodule Bacteria (Rhizobium)

Genetical and physiological studies by P. S. Nutman, detailed in previous reports, indicate that nodules are not formed at random on the roots but occur at certain points only.

Using a microscopic technique devised by Dr. Fahraeus (Uppsala)

for the continuous observation of root hairs on young growing seedlings, the infection of the root hairs of clover has been investigated. The following results were found :

1. Root-hair infection is very infrequent in *Trifolium pratense* and *T. subterranean*, about 10× more frequent in *T. ornithopodioides* and about 100× more frequent in *T. repens* and *T. fragiferum*. Other species are being investigated. The following results refer to *T. repens*.

2. In confirmation of the genetical and physiological results, it has been observed that infected root hairs are distributed in zones; these generally increase in size as the seedling ages.

3. The numbers of infected root hairs increase with time until the first nodule is formed, when they cease abruptly. At a later stage infection recommences.

4. In confirmation of Fahraeus' observations it has been found that the point of infection of the hair may be terminal or on a lateral outgrowth of the hair, and with rare exceptions is initiated in a region of deformed growth.

5. Root-hair infection appears to be stimulated by the near presence of another seedling.

The Presence and Behaviour of Rhizobium Bacteriophage in Soil and in Other Media

Janina Kleczkowska has studied the distribution of bacteriophage attacking *Rhizobium trifolii* in the field. It was only found in soil that carried clover. The strains of phage isolated were found to vary very much in the number of different strains of Rhizobium that they could attack. Some attacked 90 per cent of the strains on which they were tested. The majority of these test strains were isolated from the nodules of plants growing in the same soils from which the phages were isolated. So that phage and Rhizobium susceptible to it can coexist in a field soil.

In liquid media, on the other hand, the presence of phage and of susceptible bacteria commonly results in the elimination of the latter and in the growth of resistant variant forms of the bacteria.

In a granular medium composed of sand and vermiculite and with low nutrient supply, both phage and susceptible bacteria were found able to coexist. When the phage was present, however, variant forms of the bacteria appeared. Some of these variants differed from the parent in their effectiveness in fixing nitrogen in the host plant.

Thus the presence of phage in the soil, while not eliminating the Rhizobium, may change its behaviour towards the host legume.

BOTANY DEPARTMENT

D. J. Watson

Mr. L. H. Fernando, of the Department of Agriculture, Ceylon, came in March to work in the department for three years, with a scholarship awarded by the United Kingdom Government under the Technical Co-operation Scheme of the Colombo Plan.

Miss Joyce Watson of the Cawthron Institute, New Zealand, spent three months in the department and visited other institutes to study methods of plant analysis.

D. J. Watson contributed a paper to the Symposium on the Growth of Leaves at the Third Easter School in Agricultural Science of the University of Nottingham. He also read a paper at the Fourth Congress of the International Potash Institute held in London in August.

J. M. Thurston, K. Warington and K. J. Witts attended the Third British Weed Control Conference at Blackpool in November, and J. M. Thurston was invited to open the discussion on the control of wild oats.

Plant Nutrition

Interaction of iron and molybdenum (K. Warington)

Addition of ammonium or sodium molybdate to a nutrient solution has been shown to delay the development of chlorosis in flax when iron was supplied as ferric citrate and the initial pH was 4·6; it also delayed precipitation of iron in the solution and greatly increased iron uptake by the plants. These effects did not occur when the initial pH was 6·6 (*Rep. Rothamst. exp. Sta. for* **1955**, p. 70). This suggests that molybdenum acts by retarding the drift of pH towards neutrality, prolonging the acid conditions in which iron is more readily available, rather than by a direct interaction with iron in the solution.

The effect of molybdenum on the rate of pH change of the nutrient solution was investigated by making daily measurements on solutions containing high or low molybdenum concentrations, started at pH 4·6, 5·6 or 6·6. Observations were made at the same times on the colour of young flax plants growing in the solutions, and on precipitation of iron. Delay induced by high molybdenum supply in the development of chlorosis and in iron precipitation occurred, as before, only when the initial pH was 4·6, though there were indications of slight effects at pH 5·6, and it was always associated with a slower drift towards alkalinity. The iron content of the roots was higher in the more acid solution, and was increased still more by high molybdenum supply.

Although the maintenance of an acid reaction partly explains the effect of molybdenum, other factors are involved. When ferric chloride was substituted for ferric citrate, high molybdenum supply failed to prevent chlorosis or precipitation of iron, although the

drift in pH was almost negligible and the solution remained acid. When iron was supplied as FeEDTA in presence of high molybdenum in solutions at pH 4·6 there was little drift in pH, but in contrast with the solutions containing ferric chloride there was no precipitation of iron. Although no chlorosis developed in the low-molybdenum plants when iron was given as FeEDTA, in the presence of high molybdenum the shoots had a deeper green colour, suggesting that the effect of molybdenum was similar to that found when iron was given as citrate. This is supported by the fact that high molybdenum supply increased iron uptake by the plant from solutions initially at pH 4·6 when iron was given either as citrate or FeEDTA, but not when given as chloride.

Chelated iron complexes as sources of iron in solution culture (K. Warington)

Chelated complexes of iron with the following compounds (kindly supplied by the Geigy Company Ltd.) were tested as sources of iron in nutrient solutions, in comparison with ferric citrate :

(1) mono-sodiumethylenediamine tetra-acetate, EDTA(Na);
(2) di-sodium ethylenediamine tetra-acetate, EDTA(Na_2);
(3) diethylene triamine penta-acetic acid, DTPA;
(4) nitrilo acetic acid;
(5) *cyclo*hexylenediamine tetra-acetic acid;
(6) hydroxyethyl ethylenediamine triacetic acid, HEEDTA;
(7) gluconic acid;
(8) saccharic acid;
(9) *bis*-hydroxyethyl glycine.

In cultures initially at pH 5·5 containing 0·1 p.p.m. Fe, (1), (2), (3) and (4) were all more effective than ferric citrate in preventing chlorosis in peas, but (2), (3) and (4) caused leaf scorch when supplied at concentrations of 0·5 p.p.m., so FeEDTA(Na) was the most suitable of these four complexes. With soybean, (6) gave outstandingly good results, but (7) and (8) were no better than ferric citrate, and (9) was ineffective at concentrations below 1 p.p.m. In later tests on peas and barley with solutions containing 0·5 or 2 p.p.m. Fe initially at pH 5·5 or 7·5, FeEDTA(Na) usually gave the best plants and was effective at either pH; (5) was superior to ferric citrate in the alkaline solution, but (4) was effective only in the acid solution. FeHEEDTA and DTPA were not included in these trials, so no direct comparison of them with FeEDTA(Na) is available.

Nutrient uptake by excised roots (E. C. Humphries)

The possibility of assessing the nutrient status of a soil from the ability of roots excised from plants grown in the soil to absorb nutrients in standard laboratory conditions has been further investigated, and the chemical analyses of material from experiments already described (*Rep. Rothamst. exp. Sta. for* **1955**, p. 71) have been completed.

Barley plants were grown in pots in a nutrient-deficient soil with or without addition of a complete fertilizer, and roots were washed

out from sample pots at 5, 8 and 11 weeks after sowing. The remaining pots were kept for determination of the final yield of the crop. Analyses were made on excised root systems before and after they were transferred to Hoagland solution for 4 hours at 25° C. At the first sampling of plants that received no fertilizer, the excised roots absorbed a large amount of phosphorus but no potassium; at the second sampling there was a small uptake, and at the third a loss, of both P and K. At all three samplings there was a loss of nitrogen to the nutrient solution. This is in accord with the low phosphorus status of the soil, and shows that there was never any deficiency of N, or of K, except perhaps at the second sampling, relative to the low phosphorus supply.

Excised roots from plants that received the complete fertilizer lost N and K at the first two sampling times, but absorbed both at the third. There was a nearly uniform loss of P at all three harvests. It appears that both N and K supplies from the soil became deficient at the third sampling, near the time of ear emergence, and analyses of the whole plants showed that at this time 87 per cent of both the N and K added in fertilizer had been absorbed. Only 15 per cent of the added P was recovered in the plants at the third sampling, which accounts for the inability of the excised roots to absorb P. These results indicate that excised roots show variations in nutrient uptake from, or loss to, an aerated nutrient solution that reflect differences in nutrient supply from the soil, including deficiencies induced by removal of nutrients by the growing plants.

To test whether variations in nutrient absorption or loss by excised roots measure soil deficiencies, in the sense that they are correlated with responses to added nutrients, pot experiments were done with barley and potatoes grown in the same infertile soil as before, with nitrogen, phosphorus and potassium supplied in all combinations of three rates of each. At a suitable stage of growth samples of roots were washed out of the soil and preserved for analysis before and after transfer to a nutrient solution in standard conditions. Some pots were kept to measure the yield responses to the added nutrients. The chemical analyses of material from these experiments are not yet complete.

As part of the analysis of varietal differences in barley (p. 83) four varieties (Plumage Archer, Kenia, Proctor and Herta) were included in the 1955 soil-culture experiment to test whether their roots differ in ability to absorb nutrients, but no such differences were found, nor were there any significant differences in yield of dry matter. The same four varieties were also grown in solution-culture with two rates of nutrient supply. The rates of nutrient uptake by excised root systems were compared in standard conditions, but again no varietal differences in uptake per unit weight of root were found. In the solution-culture experiments the four varieties were grown together in competition in the same vessels; Kenia and Proctor produced smaller root systems than Plumage Archer and Herta, and gave smaller final yields and total nutrient contents. In these experiments plants that received the high rate of nutrient supply were given additional nutrients a few days before the roots were excised, and replicate blocks were sampled on successive days. Nutrient absorption by the excised roots showed a steady drift with

time over the period of sampling, presumably because of slow equilibration of the roots to a sudden change in external conditions and because the composition of the nutrient solution was also changing.

Experiments were started on the effect of removing part of the root system on subsequent growth and nutrient uptake of barley, rye and tomato plants grown in solution culture. In two weeks after treatment, nutrient uptake was reduced less than proportionally to the fraction of the root system removed, e.g., when 35 or 50 per cent of the root system was excised, the amount of K absorbed was respectively 23 and 35 per cent less than that of untreated control plants. The total weight of the plants was decreased nearly proportionally to the K uptake, so the K content per cent of dry matter was almost unaffected. Removal of roots greatly decreased the growth of the tops, but no effect on the growth of the surviving roots was observed until at least half the root system was excised.

Effect of boron on production of adventitious roots (E. C. Humphries)

Production of adventitious roots on the hypocotyl of French-bean seedlings (*Phaseolus vulgaris*) is known to depend on boron supply; it occurs if the cut hypocotyl is placed in a solution containing boron, but not in distilled water, and increases with increase in the boron concentration. As there is evidence that boron is involved in translocation of carbohydrate in plants, it seemed possible that the failure of boron-deficient bean hypocotyls to form roots might be due to restricted transport of carbohydrate from the leaves. If so, it should be possible to increase root production by increasing the carbohydrate supply.

Seedlings of dwarf French bean (var. Prince) were raised in sand and transferred to nutrient solution with or without addition of boron until the primary leaves were fully expanded. The primary leaves of boron-deficient plants were larger than those of normal plants, presumably because of reduced transport of metabolites from them, associated with the death of the apical growing point. The root and base of the hypocotyl was cut off 5 cm. below the cotyledons, and the cut hypocotyls were placed in dilute nutrient solution free from boron. The plants were kept in daylight or in complete darkness, and the primary leaves were painted daily with water, or a solution of sodium borate, or a sucrose solution, or a solution containing both boron and sucrose. The experiments are still continuing, and the results cannot yet be fully interpreted. So far, they show that boron applied to the leaves of boron-deficient seedlings increased the number of roots and root initials formed on the hypocotyls, both in the light and in the dark. Sucrose alone increased root formation in the dark, but decreased it in the light. There was no evidence that application of boron and sucrose together had a greater effect than separate applications. Plants kept in light formed roots mainly on the upper part of the hypocotyl and on the epicotyl, while in the dark most of the roots were formed on the lower part of the hypocotyl.

Weed Studies

Wild oats (J. M. Thurston)

A few seedlings of *Avena fatua* appeared in 1956 on plots where seed was sown in October 1950 at a depth of 6 inches (*Rep. Rothamst. exp. Sta. for* **1955**, p. 73), but none from the shallow sowing. For the second successive year, no seeds of *A. ludoviciana* germinated. The results indicate that *A. ludoviciana* can survive for not more than four years in Rothamsted soil, but seeds of *A. fatua* persist longer. The experiment will be continued for another year to find out whether any viable seeds of *A. ludoviciana* remain, and whether *A. fatua* seeds continue to germinate.

Observations on the longevity of wild oats seeds in land put under temporary ley were continued on three field experiments (*Rep. Rothamst. exp. Sta. for* **1955**, p. 73). In the Northampton experiment, where the soil population of a mixture of *A. fatua* and *A. ludoviciana* seeds is so high that it can be estimated by washing out the seeds from soil samples, the number of seeds recovered and presumably viable after the third year of the experiment was as great as after the second. In the previous year the number had nearly halved. The much smaller population of viable *A. fatua* seeds in the soil of the Boxworth experiment, measured by ploughing up part of the ley each year and counting the number of seedlings that appear, did not decrease during the year, the 5th under ley; in the previous year it had fallen by 75 per cent. It is possible that the population of dormant seeds in these experiments has become nearly stabilized and is now decreasing only slowly through germination or death. This must be tested by counts in future years, but the results raise doubts about the efficacy of a period in temporary ley as a method of eradicating an infestation of wild oats. In the Rothamsted experiment 3 plants of *A. fatua* per sq. yd. appeared in the spring on plots ploughed after one year under grazed ley, compared with 9 per sq. yd. in the spring of 1955 before the ley was sown. A similar reduction occurred on plots not sown with the ley, but fallowed to avoid reinfestation with wild oats seeds.

Germination tests on seeds of *A. ludoviciana* from the experiment on competition with wheat, barley and rye (*Rep. Rothamst. exp. Sta. for* **1955**, p. 74) showed the percentage of viable seeds was unaffected by the treatments. Dormancy of the first seeds was unusually high, but was slightly reduced by increased competition with the cereal crops, especially when sown early with low nitrogen supply. Nearly all the second seeds from all treatments were dormant.

The study of dormancy and periodicity of germination of types of *A. ludoviciana* and *A. fatua* distinct from those found at Rothamsted (*Rep. Rothamst. exp. Sta. for* **1955**, p. 74) was continued. As in the Rothamsted types, germination of *A. ludoviciana* ceased about the end of March (except for two selections of one type that started and finished a month later than the rest) and began again in late October. Six selections of *A. fatua* gave a spring peak of germination, like the Rothamsted type, but two selections of *A. fatua*, similar in appearance, gave a winter peak corresponding in

periodicity to the late-germinating types of *A. ludoviciana*. Thus, types of wild oats selected because they differed most widely in appearance from the Rothamsted types, usually resembled them in periodicity of germination.

The investigation of the effect of temperature on germination of seeds of *A. ludoviciana* was continued, using first and second seeds from spikelets collected in 1950, which had lost most of their natural dormancy during storage. Over 90 per cent of the first seeds germinated without pricking when kept moist at 7° or 15° C., but very few germinated at 27° C. One day or one week at 27° increased the rate of germination on subsequent transfer to 7°, but one month at 27° decreased it, and reduced the number germinating by 5 per cent. Second seeds behaved differently; 27 per cent, 17 per cent and 2 per cent germinated at 7°, 15° and 27° respectively. The initial rate of germination was higher at 15° than at 7°. Exposure to 15° or 27° for a week before transfer to 7° increased the rate of germination and raised the percentage germination to 47 per cent. The highest germination, 74 per cent, was found in second seeds held at 27° for one day and then at 7°.

Seeds of *A. ludoviciana* were collected from different positions in the panicle to determine whether their germination behaviour varies with position. Their viability and dormancy have been tested, and an anatomical examination is to be made to see whether structural differences in seed-coat or embryo can be correlated with differences in germination.

Weeds of Broadbalk (K. Warington and J. M. Thurston)

Another set of soil samples was taken from Section I of five plots of Broadbalk to compare changes in the weed-seed population on the part that is to be continuously cropped with those on the part that remains in the five-year fallow cycle (*Rep. Rothamst. exp. Sta. for* **1955**, p. 74). The species germinating in these and the previous year's samples have been recorded at regular intervals.

Broadbalk Wilderness (J. M. Thurston and K. J. Witts)

In view of a proposal to introduce grazing by sheep on part of the " meadow " section of Broadbalk Wilderness, where the growth of trees and bushes is prevented, a survey of the existing flora has been made to help decide whether the proposal is practicable and how best to divide the area, and to provide a base-line from which the changes in the flora induced by grazing could be measured. The species present and the percentage area covered by each were recorded on six occasions between April and December on quadrats distributed over the area, and the boundaries of sharply differentiated plant communities were mapped. Very few species with any grazing value were found, and useful grasses account for only a small fraction of the herbage until after the dicotyledonous weeds have died in the autumn. There are also several poisonous species, of which the most abundant is *Mercurialis perennis*. Since the last detailed description of the flora was published in 1915, the large patches of ivy that then occupied much of the area have disappeared, and so have 3 species of grasses, 9 of legumes and 19 other species; 9 species not recorded then are now present.

Physiological Effects of Virus Infection

Effects of infection on respiration and photosynthesis of tobacco leaves (P. C. Owen)

Unlike tobacco mosaic virus (TMV), which increases the rate of respiration of tobacco leaves within an hour of inoculation (*Rep. Rothamst. exp. Sta. for* **1955**, p. 75), a virulent strain of tobacco etch virus does not affect the respiration rate until the leaves show visible symptoms after 6 days or more. When tobacco plants were inoculated with tobacco etch virus, the respiration rates of inoculated or systemically infected leaves showing etch symptoms were up to 40 per cent greater than those of comparable leaves of healthy plants. This is three times the increase produced by TMV. The effect on respiration is evidently not related to the concentration of virus because the maximum concentration of tobacco etch virus in tobacco leaves is known to be only about one-thousandth of that reached by TMV. The increase in respiration caused by infection with tobacco etch virus continued throughout the life of the leaves, and occurred at all times of the year.

There was no difference in total dry weight or leaf area between healthy plants and plants infected with TMV until the second week after inoculation. After 3 weeks, when symptoms of systemic infection were visible, the dry weight of infected plants was 25 per cent less than that of healthy plants and there was a similar reduction in leaf area. The loss of dry weight caused by infection was the result of nearly equal effects on net assimilation rate and leaf area; mean net assimilation rate and mean leaf area per plant for the three weeks after infection were respectively 16 per cent and 19 per cent less for infected than for healthy plants.

Direct determinations of the rates of photosynthesis of comparable healthy and infected leaves attached to the plant and kept in daylight were made by enclosing them in perspex vessels through which air was drawn, and the CO_2 concentration of the air was measured with an infra-red gas analyser, before and after passage over the leaf. The rate of photosynthesis of leaves inoculated with TMV was decreased by 15–20 per cent of that of control leaves, and the decrease was detectable from the first hour after inoculation, at which time the virus is currently believed to be still confined to the epidermis. It also occurred from the first hour after inoculation when a purified preparation of TMV was used instead of infective sap, and when the upper epidermis (on which the inoculum was rubbed) was covered with a film of vaseline, so the effect was not due to some constituent of infected sap other than virus, nor to closure of stomata on the inoculated surface of the leaf. The rate of photosynthesis was unaffected when the virus preparation was inactivated by ultra-violet irradiation before use. These results imply that the entry of virus into the epidermis produces an effect on deeper chlorophyllous tissues within an hour, long before movement of virus out of the epidermis has been detected or inferred.

The rate of photosynthesis of uninoculated leaves of plants systemically infected with TMV 3 weeks after inoculation was about 20 per cent less than that of healthy leaves. There was a decrease

of similar magnitude in leaves infected with tobacco etch virus and showing visible symptoms.

Growth Analysis

Photosynthesis of leaf sheaths of cereals (G. N. Thorne)

In growth analyses of cereal crops it has been customary to measure leaf area as that of the laminae only, ignoring the leaf sheaths. The exposed parts of the sheaths are small compared with the laminae in the early stages of growth, but by the time of ear emergence the green area of sheaths is about equal to, and later may exceed, that of the laminae. Net assimilation rates expressed on the basis of lamina area may, therefore, be serious overestimates of the photosynthetic efficiency of the leaves to an extent depending on the relative photosynthetic rates of laminae and sheaths.

The rates of photosynthesis of single leaves and of portions of sheaths of barley plants grown in pots were measured in daylight with an infra-red CO_2 analyser. The rate of CO_2 absorption per sq. cm. of sheath was about half that per sq. cm. of lamina. Young leaves had a higher rate than old leaves; the rates of CO_2 uptake per sq. cm. of lamina or sheath of a particular leaf were about 70 per cent of those of the next higher leaf on the stem.

The rate of respiration, measured at night in one series of experiments, was two to three times greater per unit area of sheath than of lamina. This difference was due mainly to the greater dry weight per unit area of the sheaths, but respiration per g. dry weight was slightly greater for sheaths than for leaves. The difference between sheath and lamina in respiration rate per sq. cm. was of the right order to account for the difference in apparent photosynthesis.

Varietal differences in yield of barley (G. N. Thorne)

In the 1955 field experiment comparing Plumage Archer, Herta and Proctor barleys with and without nitrogenous fertilizer (*Rep. Rothamst. exp. Sta. for* **1955**, p. 76), the total dry weight yield, leaf-area index and net assimilation rates were similar for all varieties throughout the growth period. The higher grain yield of Proctor and Herta was therefore not due to increased size or efficiency of the photosynthetic system, but to a difference in the distribution between ears and shoots of the products of photosynthesis after ear emergence. In the early stages of growth, Plumage Archer had more tillers than the other varieties, but many of them died while the other varieties were still producing ear-bearing shoots. Consequently, Proctor and Herta had more ears at harvest than Plumage Archer, and this accounts for their higher grain yield, though the difference was partly offset by the larger ear and grains of Plumage Archer. Whether the tendency for a higher fraction of assimilate to move to the ears is causally related to the development of more ears is not known. Increased photosynthesis by the larger number of ears probably contributed towards the higher yield of grain. The progress of nutrient uptake throughout growth was similar in all varieties, but Herta took up phosphorus more slowly than the others.

In the pot experiment (*Rep. Rothamst. exp. Sta. for* **1955**, p. 77),

Plumage Archer produced more leaf area and total dry matter than Proctor, Herta or Kenia; the reason for this difference from the results of the field experiment is not known. But, as in the field, Plumage Archer transferred a smaller fraction of total dry matter to the grain, and so the yield of grain was similar for all varieties. The main point of the experiment was to determine whether the contributions made by photosynthesis in different parts of the plant to the dry matter that enters the grain vary with variety. Photosynthesis in the ears of some plants was prevented by covering them with opaque shades, and other plants had the awns cut off, or the lower leaves and stems shaded. The results were independent of variety or nitrogen supply; about 25 per cent of the dry matter in the grain was produced by photosynthesis in the ears, including 10 per cent from the awns, while photosynthesis in leaves and stem below the flag leaf supplied about 15 per cent. The balance, some 60 per cent, must have come from flag leaf and peduncle, and these are evidently the most important sources of dry matter entering the grain in all the varieties tested.

Effect of time of application of nitrogenous fertilizer to barley (G. N. Thorne and S. A. W. French)

A pot experiment on wheat (*Rep. Rothamst. exp. Sta. for* **1955**, p. 76) indicated that late nitrogen applications are ineffective on plants that previously had a very low N supply. To test whether this is true for spring cereals, barley was grown in pots with the following treatments: no N, single dose of N applied at sowing or at ear emergence, double dose of N applied at sowing or equally divided between sowing and ear emergence. Plumage Archer and Proctor were included in the experiment, to confirm and extend previous work on the physiology of their differences in growth and yield. Ears on half the pots were covered with opaque shades immediately after they emerged, to test the effect of early and late N supply on photosynthesis by the ears.

The single dose of N at sowing greatly increased the grain yield of both varieties, but when given at ear emergence it had no effect. This is similar to the results for wheat. In pots that already had the single dose of N at sowing, addition of the second dose at sowing increased the grain yield of Proctor, but not of Plumage Archer, but when the second dose was given at ear emergence it had no effect on the grain yield of Proctor, but increased that of Plumage Archer. As in earlier experiments, Plumage Archer had more shoots than Proctor early in the growth period but subsequently more died, so that Proctor eventually had more shoots and ears. The first dose of N increased the number of ears of both varieties whether applied early or late; the second dose at either time increased the shoot and final ear number of Proctor but caused only a small temporary increase in shoot number of Plumage Archer. Evidently response in grain yield to late N applications does not depend on increased shoot or ear production. The difference between varieties in response to N requires confirmation, and the separate contribution to grain yield of shoots produced before and after the time of late N application needs to be determined in future experiments. Shading the ears decreased the grain yield of both

varieties by 27 per cent on the average of all treatments. The percentage varied with time and rate of N supply, but the analysis of these results is not yet completed.

Effect of varying soil moisture deficit on plant growth (P. C. Owen)

In two more experiments on sugar beet, grown in Mitscherlich pots, the moisture content of Rothamsted soil was either kept near field capacity by frequent watering or allowed to fall to about pF 4 before return to field capacity. The results confirmed that variation within this range had no effect on total dry matter production (*Rep. Rothamst. exp. Sta. for* **1955**, p. 77). The drier conditions slightly decreased leaf area per plant and the amount of water transpired per plant, but did not affect water loss per unit leaf area. Twice-daily wetting of the leaves with a fine spray was tested in one experiment but had no effect on growth.

It has become apparent that pot cultures are unsatisfactory for this work, because the total amount of water available from the soil is small compared with that available to a plant of a field crop, and conditions of water stress can be maintained only for short periods before the plants must be watered to survive. Pot cultures have therefore been abandoned, and future work will be done on small plots under a glass roof to protect them from rainfall.

Further work on the effects of irrigation on the growth of sugar beet in the Woburn Irrigation Experiment was planned, but abandoned after the first sampling on 10 July. At this time the early irrigation had had no effect in spite of the dry spring. No further irrigation was done because of heavy rainfall during the next two months.

An attempt to increase yield by controlling leaf area index (D. J. Watson, S. A. W. French and G. H. King)

An attempt was made in 1955 (*Rep. Rothamst. exp. Sta. for* **1955**, p. 78) to increase the total dry matter yield of a field crop of kale by preventing the leaf area index (L; leaf area per unit area of land) rising above the optimum for dry matter production by thinning the crop at intervals from mid-July onwards. Previous experiments had shown that the rate of dry matter production per unit area of a kale crop was maximal when L lay between 3 and 4; for the unthinned crop in 1955 L rose nearly to 6 in August. On the thinned plots, the total dry matter yield, including thinnings, was only 6 per cent higher than on the unthinned plots. As it seemed possible that the thinning had been too severe, the experiment was repeated in 1956 with two thinning treatments, aimed at holding L between 3 and 3·5 or between 3·5 and 4, but with both the range of L achieved was slightly wider. Although as before the thinned plots had a higher net assimilation rate than the unthinned, it was only just sufficient to offset the decrease in L, so that eventually thinned and unthinned plots gave almost identical total dry matter yields. Part of the explanation for the lack of response to thinning may be that L of the unthinned crop was smaller for the 1956 crop, and did not exceed 5 until the end of August, so the effect of thinning on L was relatively smaller than in 1955. But the reason for the precise

compensation for decreased leaf area index by increased net assimilation rate is not clear, and further examination of the data is needed.

Net assimilation rate of cultivated and wild beets (K. J. Witts)

Although net assimilation rate has been shown to vary within species, present knowledge suggests that there is little hope of increasing the efficiency of the photosynthetic process by selection or breeding. If it is possible, it might reasonably be expected to have occurred during the development of cultivated sugar beet by selection from its wild ancestors, which were probably types of *Beta vulgaris* subsp. *maritima*. An opportunity to test this was provided by the collection of wild beet made by J. W. Blencowe, of the Plant Pathology Department, and grown from seed on the Garden Plots in 1956, in comparison with Kleinwanzleben E sugar beet.

Three wild types were selected, one from Pembroke, where there is little chance of crossing with cultivated beet, and two from Norfolk. Samples of plants of these three types and of Kleinwanzleben E sugar beet were taken on three occasions in July and August, and measurements were made of total dry weight and leaf area from which the net assimilation rates for the two intervals between samplings were calculated. Two of the wild types had mean net assimilation rates nearly identical with that of Klein E. The third wild type, one of the two from Norfolk, had a net assimilation rate equal to that of Klein E in the first period, but significantly less than Klein E in the second period. The reason for this difference is not known, but the results show that some wild beet plants have as high a net assimilation rate as the highest-yielding commercial strain of sugar beet, indicating that prolonged selection for high yield in this species has not increased the photosynthetic efficiency of the leaves.

Leaf growth (L. H. Fernando)

A pot-culture experiment on sugar beet was done to investigate the effect of nitrogen, phosphorus and potassium on leaf growth. Previous work on several crops has shown that while nitrogenous fertilizer increases leaf area per plant throughout the growth period, phosphatic fertilizer is effective mainly in the early stages, and may subsequently decrease leaf area, in contrast with potassic fertilizer, which increases leaf area in the later stages of growth. The object of the experiment was to analyse these effects of nutrient supply on leaf area per plant in terms of the rate of leaf production, the longevity of leaves and the rate of expansion and ultimate size of individual leaves.

In another series of experiments on sugar beet and tobacco, factors that influence the size of a particular leaf (usually for convenience the 6th) in the series produced from the apical meristem were studied, with particular reference to the influence of neighbouring leaves and its interaction with nutrient supply. Analysis of the results of these experiments is not yet completed.

Methods

Measurement of soil pF by means of the Peltier effect (P. C. Owen in collaboration with J. L. Monteith, Physics Department)

A method of measuring the suction pressure of plant tissue based on the Peltier effect has been described by Dr. D. C. Spanner of Bedford College (*J. exp. Bot.* **2** (1951), 145–168). Some preliminary work to adapt the principle for measurement of soil pF was done in the Physics Department by P. B. Flegg (*Rep. Rothamst. exp. Sta. for* **1955**, p. 40), and an instrument has now been assembled that can determine very accurately the Relative Humidity of the atmosphere in equilibrium with a sample of soil in a small sealed vessel. From this the total water potential and pF of the soil can be computed. Some calibration problems and investigation of the cause of irregularities probably due to stray e.m.f.s in the system remain to be dealt with, but the method was sufficiently reliable to be used for determining the soil-moisture limits representing the prescribed pF range in the experiments on the effect of varying soil-moisture deficit on growth (p. 38). The instrument could be used in other biological work that requires very precise measurement of Relative Humidities between 98 and 100 per cent, or of small changes in total osmotic concentration of solutions.

BIOCHEMISTRY DEPARTMENT

N. W. Pirie

The Biochemical Society paid its first visit to Rothamsted and held an all day meeting here on 25 May. The farm and several departments arranged demonstrations of aspects of their work. N. W. Pirie attended a Conference on Chromosomes at Wageningen and a symposium arranged by the New York Academy of Sciences on Modern Ideas on Spontaneous Generation.

Plant Enzymes

Enzymes of bracken (R. H. Kenten)

Thiaminase is present in bracken and other Pteridophytes but absent from a large number of species of higher plants, and it is possible that this difference might be exploited for the development of specific bracken-killing agents.

Thiaminases catalyse the fission of the methylene–quaternary nitrogen bond of thiamine. The fission may be hydrolytic (equation 1), or transfer of the pyrimidine moiety of thiamine to an amine acceptor (equation 2) may take place.

$$P\text{–}CH_2\text{–}^{+}T + H_2O \longrightarrow P\text{–}CH_2OH + T + H^{+} \quad . \quad . \quad (1)$$

$$P\text{–}CH_2\text{–}^{+}T + R\cdot NH_2 \longrightarrow P\text{–}CH_2\text{–}NH\cdot R + T + H^{+} \quad . \quad (2)$$

P and T stand for the pyrimidine and thiazole components of thiamine respectively. Thiaminases are known which catalyse both the hydrolytic and transfer reactions or the transfer reaction alone. With extracts of bracken the destruction of thiamine was negligible compared to that found when certain amines were added. Such an effect was most likely due to the added amine taking part in the transfer reaction rather than accelerating hydrolytic fission, but it was clear that this could only be decided unequivocally if a method was available for determining the pyrimidine–amine product. Tests with a variety of amines suggested that bracken thiaminase catalysed the transfer reaction between thiamine and pyridine most readily. This reaction leads to the formation of 1 mol *N*-(-2-methyl-4-aminopyrimidyl-(5))-methylpyridine (heteropyrithiamine) per mol of thiamine destroyed, and can be followed by measuring the rate of formation of heteropyrithiamine. A method of estimating small amounts of heteropyrithiamine in the presence of thiamine has therefore been worked out. It depends on the destruction of thiamine by incubation with strong alkali and subsequent oxidation of heteropyrithiamine to 2-methylpyrichromine by ferricyanide. The 2-methylpyrichromine is estimated spectrophotometrically at 386 mμ. Using this method of determining heteropyrithiamine, conditions suitable for the measurement of bracken thiaminase transfer activity have been established. Under these conditions, with crude bracken extracts in the presence of pyridine, the conversion of thiamine to heteropyrithiamine is virtually quantitative,

showing that no significant destruction of thiamine by side reactions takes place. The method of determining thiaminase transfer activity has been used successfully with two other ferns, and may prove generally useful with plant and animal extracts. No activity has been found so far in the few species of higher plants examined.

Concentrated and partially purified preparations of thiaminase have been made from water extracts of air-dried bracken fronds by fractionation with ammonium sulphate and calcium phosphate gel. Such preparations are capable of catalysing, in the presence of pyridine, the destruction of 400–1100 mg. thiamine per hour per mg. N. Tests with relatively large amounts of these concentrated preparations in the absence of pyridine, over a wide range of pH, have failed to indicate the presence of a thermolabile factor capable of destroying thiamine. Mn^{2+} has been reported to stimulate the action of certain animal thiaminase preparations, but after incubation with small amounts of Mn^{2+} the bracken thiaminase preparations still gave negative results for hydrolytic activity and the transfer activity was not affected. It can be seen from equations 1 and 2 that when thiaminase catalyses either the hydrolytic fission or the transfer reaction with primary and secondary amines a H^+ is released. With tertiary amines the pyrimidine–amine product retains the quaternary nitrogen configuration and no release of H^+ takes place. The hydrolytic or transfer reaction of thiaminase with primary and secondary amines can be studied manometrically in bicarbonate buffer and N_2–CO_2 atmosphere by measuring the CO_2 output which accompanies the release of H^+. By this technique no evidence of the hydrolytic fission of thiamine by concentrated bracken thiaminase preparations in the absence of added amines was found, but a number of primary and secondary amines have been studied, and the results suggest that among others the amines ethanolamine, tyramine, taurine and piperidine, all of which are known to occur in plant material, can take part in the thiaminase-catalysed transfer reaction. The manometric technique suffers from the disadvantages that only a narrow range of pH can be studied and that the presence of amines can cause CO_2 retention, the extent of which varies with the dissociation constant and amount of the particular amine present. When the amine is strong, e.g., piperidine, or very weak, e.g., aniline, even when large amounts ($0{\cdot}1M$) are present, CO_2 retention is small and 85–100 per cent of the thiamine destroyed can be accounted for by the evolution of CO_2. In spite of the disadvantages, the method has been studied because it should be possible to test with it the action of thiaminase on compounds of similar structure to thiamine but for which analytical methods are not available. Hence it may prove useful in the studies of the substrate specificity and structural inhibitors of bracken thiaminase which are in hand.

Plant enzyme reactions leading to the formation of heterocyclic compounds (A. J. Clarke and P. J. G. Mann)

We have already reported the formation of unsaturated pyrrolidine and piperidine compounds by oxidation of putrescine, cadaverine and lysine. We now find that the oxidation of agmatine and ornithine, catalysed by the enzyme, results in the formation

of unsaturated pyrrolidine compounds. The product of ornithine oxidation is probably Δ′-pyrroline-2-carboxylic acid; it is converted to proline by catalytic hydrogenation.

The oxidation of the diamino acids ornithine and lysine is catalysed much less readily by the enzyme than that of the diamines of the same hydrocarbon chain length. It is likely that the carboxyl group inhibits the formation of the enzyme substrate complex probably by repelling another acidic group on the surface of the enzyme. If the carboxyl groups of these amino acids are masked by forming the methyl esters, the rates of oxidation are increased about sevenfold. The products of the oxidation of these esters undergo spontaneous cyclization, yielding the methyl esters of Δ′-pyrroline-2-carboxylic acid and Δ′-piperideine-2-carboxylic acid.

We have already reported evidence suggesting that when the oxidation of putrescine and cadaverine, catalysed by plant amine oxidase, is carried out in the presence of reactive methylene compounds condensation takes place between the reactive methylene compounds and the unsaturated ring compounds formed as a result of the oxidation of the amines. These reactions are of interest, since, with appropriate reactive methylene compounds, the condensations should produce pyrrolidine and piperidine alkaloids. We have now been able to prove that this is the case by the isolation and identification of the products of two such reactions. The two alkaloids so far prepared are norhygrine (2-acetonylpyrrolidine) and *iso*pelletierine (2-acetonylpiperidine), which are formed by the oxidation of putrescine and cadaverine respectively, in the presence of acetoacetate. The results support the suggestion that the formation of pyrrolidine and piperidine alkaloids depends on the spontaneous condensation of plant metabolites with the unsaturated ring compounds.

The oxidation of pyridoxine and allied compounds by peroxidase systems (A. J. Clarke and P. J. G. Mann)

The fact that plant amine oxidase is inhibited by carbonyl reagents has led to the suggestion that a pyridoxal compound may be the prosthetic group of the enzyme. Evidence apparently supporting this suggestion has been obtained by other workers, who have shown that when plant saps containing the amine oxidase are dialysed for several days with the object of removing the prosthetic group, the subsequent rates of oxygen uptake of the dialysed saps in the presence of added amines are increased by the addition of pyridoxal hydrochloride. During attempts to establish the nature of the prosthetic group we have been able to confirm these observations with pyridoxal hydrochloride and have obtained similar effects with pyridoxal phosphate, pyridoxamine dihydrochloride and pyridoxine hydrochloride. Our results suggest that the increased oxygen uptakes are due to oxidation of these compounds rather than to activation of the apo-enzyme of the amine oxidase. This oxidation is brought about by the hydrogen peroxide produced during the oxidation of the amines, and is catalysed by the peroxidase of the plant saps. It results in increased oxygen uptakes, since in absence of the pyridoxine compounds the hydrogen peroxide is decomposed by the catalase of the plant saps. The effect is best

shown in those plant saps where the ratio of peroxidase to amine oxidase is high. It is not obtained with purified amine oxidase preparations of low peroxidase content, but can be demonstrated with such preparations, in presence of catalase, if peroxidase is added. It is only dependent on the amine oxidase reactions in so far as these constitute a source of hydrogen peroxide. The oxidation of glucose catalysed by glucose oxidase also produces hydrogen peroxide, and with this system, in presence of peroxidase and catalase, the addition of pyridoxine compounds causes increased oxygen uptakes. Finally, in reaction mixtures of the pyridoxine compounds and peroxidase with direct addition of hydrogen peroxide the oxidation can be demonstrated by spectrophotometric methods. These observations diminish the relevance of this piece of evidence that plant amine oxidase is a pyridoxal enzyme. We have so far been unable to establish the nature of the prosthetic group, but we have obtained other indirect evidence suggesting that it contains pyridoxal phosphate. This depends on the fact that the rate of inhibition of the enzyme by *iso*nicotinyl hydrazide is the same as that of glutamic decarboxylase, a known pyridoxal enzyme. Other workers have suggested that the inhibition of pyridoxal enzymes by *iso*nicotinyl hydrazide is due to the formation of pyridoxal phosphate *iso*nicotinyl hydrazone and that the rate of inhibition should be constant for all pyridoxal-requiring enzymes. We still adhere to the view expressed in the Report for 1954 that there is also a metal in the prosthetic group of the amine oxidase.

Polyphosphatase (W. S. Pierpoint)

Gradient elution chromatography on a cation-exchange resin resolves the polyphosphatase from pea leaves into two fractions. Both these fractions are present in dialysed extracts of pea leaves, and therefore are not products of the " purification " procedure to which the extracts are subjected. Nor are they products of the chromatographic procedure itself, for each behaves as a single homogeneous substance when rechromatographed separately. The two fractions have the same pH optimum, are not affected by some metal ions or chelating agents, have similar heat stabilities and differ only qualitatively in their specificities. This suggests that they are not different enzymes, but rather slightly different forms of the same enzyme. The phosphatase is not unique in this respect, since several other biologically active proteins consist of two or more active components. We do not know whether the different forms of these proteins exist *in vivo* or are autolytic artifacts produced during the disintegration of the tissues.

Some attention has been paid to the specificity of the phosphatase in view of its possible use as an analytical tool in the analysis of polyphosphate compounds. It will liberate orthophosphate from tripolyphosphate, adenosine-5′-phosphate (AMP), adenosine-5′-triphosphate (ATP), ribonucleic acid from various sources, a mixture of adenosine-2′- and 3′-phosphates, and a mixture of uridine-2′- and 3′-phosphates. Although it breaks the diester bonds in trimetaphosphate, it will not break those in tetrametaphosphate, diphenylphosphate or the nucleic acids. The enzyme therefore has unspecific phosphomonoesterase activity and a more specific

diesterase activity, and will be of only limited use as an analytical tool. It is very unlikely that the diesterase activity is due to a contaminating protein, since it cannot be separated from the monoesterase activity by a wide range of protein separation techniques.

Chemical Studies on Materials of Biological Importance

Polyphosphates (W. S. Pierpoint)

A number of phosphorus-containing materials of biological importance, including such diverse materials as pea leaves, bee intestines, phosphate rocks and the excreta of certain insects, have been tested for the presence of inorganic polyphosphates. The method used was a chromatographic one which will separate those phosphates, both linear and cyclic, containing less than six phosphate groups.

The excreta of the Greater and Lesser Wax-Moths, *Galleria mellonella* and *Achroia grisella*, were tested, as they are the only materials derived from the tissues of higher animals in which appreciable amounts of polyphosphate are known to occur. Large amounts of these materials were available from the Bee Department.

The excreta from *G. mellonella* contains about 0·6 per cent of its dry weight as phosphorus, and about $\frac{2}{3}$ of this is water soluble and composed mainly of inorganic polyphosphates. A typical analysis suggests a composition of 14 per cent orthophosphate, 23 per cent pyrophosphate, 44 per cent tripolyphosphate, and the residue of more highly polymerized polyphosphates and unidentified organic phosphates. Although the material from *A. grisella* contained more phosphate on a dry-weight basis (about 0·8 per cent), the composition of the inorganic phosphate fraction was very similar to that of the other insect. This similarity of composition argues against these low-molecular-weight compounds having been formed as a result of bacterial or enzymic decomposition after the excreta were voided. Moreover, the excreta are not a suitable medium for enzymic activity, as they contain only about 1 per cent of water. Direct attempts to observe a polyphosphatase activity in aqueous extracts gave negative results.

It has so far proved impossible to detect any of the smaller polyphosphates in pea-leaf extracts. If they are present at all they must account for less than 2 per cent of the total phosphate present. Similarly, none could be detected in extracts of the ventriculi of honeybees, although these organs are known to contain large numbers of intracellular particles which are very rich in phosphorus.

The organic acid content of sugar-beet leaves (G. H. Wiltshire)

Oxalic acid was found to be present in large quantities in sugar-beet leaves, together with smaller amounts of citric, malic and fumaric acids. Leaves which had been wilted for 1, 3 or 10 days contained the same acids in much the same proportions, but, because of the loss of water by evaporation and of solids by oxidation, wilted leaves contained 2·1 g. oxalic acid per 100 g. fresh weight, as compared with 0·3 per cent in unwilted leaves. Thus an animal fed on

wilted sugar-beet leaves eats as much or more oxalic acid as one feeding on fresh leaves, and in so far as conclusions can be drawn from the experiment, it would appear unlikely that oxalic acid is the toxin in unwilted sugar-beet tops. It would appear, therefore, that there is no foundation for the widespread belief that oxalic acid is the cause of scouring when sugar-beet leaves are fed to cattle and that the advantage of wilting depends on oxalic acid destruction.

The potato-root eelworm hatching factor (G. H. Wiltshire)

The Nematology Department has provided us with three or four hundred litres of Root Diffusate (R.D.) this year. Most of this was from plants grown in pots of sand watered with nutrient solution, some from plants in soil and some from plants grown in nutrient without sand or soil. The latter was the most active. The average L.A. value (log concentration in arbitrary units) was about 3, and the dry-matter content about 0·46 g./l. If activity is expressed in the same arbitrary units, 1 litre of R.D. of L.A. 3 contains 1,000 activity units, and its specific activity on a dry-matter basis is 2·18 units/mg.

The R.D. was acidified and shaken with 1 g. partly deactivated charcoal/l. The charcoal was recovered on a basket centrifuge, washed, dried and eluted with acetone. An average of 55 per cent of the active material was recovered by concentration of the eluate to dryness, but recovery was occasionally as low as 20 per cent. The proportion of factor adsorbed could be increased from about 90 to 99 per cent by increasing the amount of charcoal to 10 g./l., and was reduced by decreasing the amount to 0·1 g./l. The optimum recovery was got at a rate of 1–2 g./l.

Dried acetone eluate could be stored at room temperature in the desiccator without loss of activity. The specific activity of several preparations ranged from 100 to 1,100 units/mg. Further purification was achieved by solution in dilute hydrochloric acid, transfer to *n*-butanol and return to aqueous sodium bicarbonate. The best preparation had a specific activity of 8,300 units/mg., and produced the same hatch as untreated R.D. at a concentration of $0{\cdot}5 \times 10^{-6}$. This preparation, which is probably not homogeneous, has an apparent pK of 5·1 and equivalent weight about 200. It is soluble in water, and can be transferred from acidified solution into immiscible organic solvents and recovered by extraction into bicarbonate. It migrates towards the anode on paper electrophoresis, and on paper chromatograms moves at the front in several solvents. It can be recovered from chromatographic partition columns, and the activity is associated with a titratable acid in the effluent. Every preparation so far made shows a blue fluorescence under ultra-violet light, but most of the fluorescent material in the acetone eluate is not associated with hatching activity. It appears to have no absorption band between 200 and 300 mμ.

The hatching activity of acid aqueous solutions kept at +2° or at room temperature is reasonably stable, and activity is not much reduced at any pH up to 9, but in 0·1*N*-sodium hydroxide activity is lost within seconds at room temperature and cannot be restored by neutralization. It is probably for this reason that recovery from a weakly-basic anion-exchange resin is better than from strongly

basic resins. The factor is not adsorbed on cation-exchange resins.

Activity is reduced to one-tenth by boiling in 1*N*-hydrochloric acid for 5 minutes. It is not reduced by warming with sulphurous acid.

Plant Viruses

Factors affecting the infectivity of plant viruses (N. W. Pirie)

The mitochondrial fraction made from tobacco leaves infected with tobacco necrosis virus contains a system that, *in vitro*, robs purified virus of its infectivity. The material that is actually responsible for the disinfection diffuses through cellophane, and it withstands drying and boiling. It is present in the successive supernatant fluids made by sedimenting the mitochondria repeatedly from water. This could happen because the material is slowly released, but it is more probable that it is made continuously by an enzymic process. There is no inactivation if air is excluded or if the mitochondria have been heated. Extracts are ineffective if the mitochondria have been frozen or exposed to chloroform. In the presence of leaf sap there is no inactivation; it is therefore unlikely that the system controls infectivity *in vivo*, but it gives a satisfactory explanation for many of the variations in infectivity that we have already described with this virus.

Mitochondria from uninfected leaves also inactivate but much less strongly; those from leaves infected with tobacco ringspot virus, on the other hand, inactivate both necrosis virus and ringspot virus. None of these preparations seems to affect tobacco mosaic virus. The mechanism of these inactivations is obscure, but they can be simulated by low concentrations of several substances (ascorbic acid, citrate and some aldehydes), and the effect may well not be specific.

From many different laboratories evanescent infectivity has been reported in fragments from tobacco mosaic virus; there is therefore increased interest in the infectivity of particles shorter than the canonical 300 mμ. We confirm the infectivity of some TMV fractions that contain predominantly nucleic acid and find that this infectivity is lost on exposure to leaf ribonuclease. This may mean that nucleic acid can be infective in the absence of other virus components; this has been claimed, but has not been firmly established. Ribonuclease is detectable in all TMV preparations; some TMV fragments inhibit the infectivity of both intact TMV and the infective nucleic acid fractions; the stability of the infectivity of fractions depends greatly on the other components of the system. There are therefore ample factors to create a situation in which the unequivocal interpretation of infectivity results is difficult. It may be wise to regard claims that TMV has been resynthesized from non-infective split products as plausible rather than substantiated. (With F. C. Bawden.)

The susceptibility of French beans to infection with tobacco necrosis virus (G. H. Wiltshire)

In 69 tests of the effect of darkening on susceptibility over the past three years, there was an increase in 48 and a reduction in 21. This variability has made it difficult to explore the possible connection between the effects of darkening on composition and on susceptibility. Some of it may be ascribed to differences in season and weather, especially to differences in illumination and temperature. An integrating photometer has been constructed, and tests with it are in progress. Temperature differences between darkened and control plants have been reduced by use of a much larger dark hood with adequate ventilation, and where possible, one leaf of each plant has been darkened by covering with aluminium foil and the other leaf used as a control.

There is generally an inverse relation between carbohydrate content and susceptibility in comparisons of older and younger plants on the same date, summer-grown and winter-grown plants, and control *vs.* darkened plants. Over a short period, however, as, for instance, in plants inoculated at different times on the same day and plants kept at elevated temperatures for a few hours, susceptibility may vary in the same sense as carbohydrate content or be apparently unrelated to it. Covering the underside of the leaf with a thin film of gum, which reduced carbohydrate content by blocking the stomata, always reduced susceptibility, but the water content was also increased by this treatment.

It was not possible to increase the carbohydrate of leaves on the plant by more than 20 per cent by infiltration of sugars, probably because the extra sugar was transferred to the stem and roots. Sucrose infiltrated together with potassium phosphate for 3 days before inoculation reduced susceptibility of darkened leaves, but did not alter that of illuminated leaves. Sucrose alone had no effect, whereas glucose produced a small increase in susceptibility. The effect of sucrose with phosphate, together with the effects of darkening and of restriction of carbon dioxide supply, make it likely that susceptibility depends, in part, on the content of some photosynthetic product. It is, however, not directly related to the content of carbohydrate because infiltration of 2-4-dichlorophenoxyacetic acid reduces susceptibility of darkened leaves and at the same time has little effect on carbohydrate content.

Plants kept at constant 24°, 30° or 36° before inoculation were more susceptible and contained less carbohydrate than plants in the uncontrolled glasshouse, which fluctuated between 8° and 38°. Raising the temperature to 36° for as little as 2 hours doubled the number of lesions produced. It might be expected that the temperature and illumination factors would interact, resulting in a daily fluctuation of susceptibility. Such a diurnal cycle, with maxima at 4 a.m. and 4 p.m., was in fact found in the glasshouse without temperature control, but at constant 36° susceptibility declined steadily, and at 24° and 30° the diurnal cycle was less marked. A diurnal cycle of carbohydrate content with a single maximum was not apparently related to the times of maximum susceptibility.

Large-scale Production of Leaf Protein

(M. Byers, D. Fairclough and N. W. Pirie)

No radical changes in the equipment or in the way in which it is used were made during the summer, but with the end of the cropping season a complete reorganization has been begun so as to make full use of a new shed and new equipment. Rye, wheat, oats, tares, lupins, serradella and birdsfoot trefoil have been added to the list of crops processed. The most interesting feature of the results is the high quality and ready extractibility of the protein from young cereals, even when the crop has a low N content. Thus barley containing only 2·5 per cent N (on the dry matter) gave a yield of protein, containing 11 per cent N, accounting for half the crop N. Work on other species presaged poor yields of mediocre protein from leaf with such a low protein content. Yields as high as this cannot be attained if the water initially in the leaf is relied on to bring out the liberated protein. The effects have therefore been studied of different ratios of crop to added water, and of the addition of alkali and sodium sulphite to the water, on the yield and efficiency of the process. A few figures are collected in the table showing the increased extraction got by adding water.

Table 1

Effect of pulping, with and without added water

					Without Water		With Water		
	Date	Dry matter, %	N on dry matter, %	Pulper speed, r.p.m.	Protein N in the extract crop N, %	Protein N per kw.hr. pulper, g.	Water added per 112 lb. crop, lb.	Protein N in the extract crop N, %	Protein N per kw.hr. pulper, g.
Cocksfoot	15 May	23·8	2·7	950	4·6	11·6	66	33·8	46·0
Grass	31 July	21·5	3·37	950	10·15	10·7	140	49·0	57·2
Lucerne	24 Oct.	25·7	2·16	950	29·55	64·1	60	40·6	78·4
Rye	29 May	21·7	1·5	950	27·6	18·6	65	47·5	55·9

The occasional use of alkaline extraction fluids and the wide range of crops have forced us to control the pH of the extract when it is coagulated and filtered. For easy filtration it should not be more alkaline than pH 5·8 (sugar beet can be 6·5 without added alkali), so that an adjustment before coagulation is often needed. As a routine the protein is pressed until the DM rises to 40 per cent, resuspended in 20 times its weight of water, the pH is adjusted to 4·0 before filtering and pressing again. After this amount of washing less than 1 per cent of the DM of the protein cake can be extracted with cold water.

The protein is compressed into hard blocks that are perishable and have to be kept sterile or under refrigeration. Much of the material has therefore been dried and defatted; it is convenient to combine the processes by using acetone as extractant. This solvent has the advantages of easy separation from water and low boiling point, but losses with our present discontinuous arrangements are high. The extracted lipid is being kept in case anyone has a use for it.

After extraction, the protein contains about its own weight of acetone, and the texture of the final product depends on the condi-

tions under which this is removed. The best of the many arrangements tried is to pack the protein loosely into a tube that can be warmed and that is connected to a receiver at −20°. At 60–100 mm. pressure the acetone comes off without great shrinkage and hardening of the protein. The final traces are removed at a lower pressure or by ventilation.

In this way the protein appears as a soft powder, dark grey when made from grass, pale from cereals and faintly green from kale or tares. With care the N content can be kept consistently above 10 per cent; 12 per cent is about the best attainable at present. *In vitro* it is 40–55 per cent digestible by enzymes such as commercial trypsin and pepsin, and so resembles many other proteins in feeding-stuffs. The reasons for the lower digestibility of bulk leaf protein compared with some leaf-protein fractions and the commonly handled proteins, such as casein, is being studied, for it is of both theoretical and practical interest.

PLANT PATHOLOGY DEPARTMENT

F. C. Bawden

With the increased space gained by the mycologists moving to the West Building, more visitors can be accommodated, and there are now six working in the department: J. T. Slykhuis from Canada, J. G. Bald and M. Chessin from the U.S.A., R. S. Badami from India, and A. J. Gibbs and D. A. Perry from the U.K.

H. L. Fisher left to become chemist at F. W. Berk & Co. L. J. Cook was appointed to work on foot rots of cereals. D. H. Firth left the Dunholme Field Station, where he was replaced by E. C. W. Dunham. S. N. Adams was appointed to a new post of soil chemist there. Making a chemical laboratory and building new cloak rooms progressed so slowly that work in the laboratory was almost prohibited for most of the year.

Marion Watson attended the International Entomological Congress in Montreal, R. Hull and J. W. Blencowe the Institut International de Recherches Betteravières Virus Yellows Colloquium in the Netherlands, L. F. Gates the I.I.R.B. 19th Congress in Belgium and D. H. Firth the I.I.R.B. summer meeting in France. At the invitation of their Departments of Agriculture, Mary D. Glynne visited Eire and Northern Ireland to survey cereal crops for eyespot disease, which in Eire is more damaging and less easy to control than in England. F. C. Bawden also visited Eire, to lecture at University College, Dublin.

I. Mactarlane was awarded the Ph.D. degree of London University.

Viruses and Virus Diseases

Work on a virus-inactivating system present in small quantities in healthy tobacco plants and in larger amounts in plants infected with the Rothamsted tobacco necrosis virus or with tobacco ringspot virus, is described in the report of the Biochemistry Department. There also is described other joint work with N. W. Pirie showing that the protein fragments produced by disrupting tobacco mosaic virus (TMV) with alkali are inhibitors of infectivity, and suggesting that the nucleic acid of TMV, when newly separated by treating the virus with phenol, is infective, though much less so than intact virus.

Last year we reported on an unusual strain of TMV, unusual because it infects leguminous plants systemically, but even more so because its physical and serological properties differ greatly, depending on whether the virus is obtained from systemically infected tobacco or French bean plants. Amino-acid analyses (made at the Biochemistry Department, Cambridge University) of purified virus preparations from the two plants showed considerable differences, of which the most striking was the presence of histidine in preparations from beans but not from tobacco as ordinarily grown.

When tobacco plants inoculated with the virus from beans are grown at temperatures above 30° C., however, the usual tobacco form is not produced; the virus then has the pathological and serological qualities of the usual bean form and it also contains histidine. (Bawden.)

The electrophoretic patterns of sap from normal and virus-infected leaves

Infecting tobacco plants with TMV characteristically alters the electrophoretic pattern of clarified leaf sap by adding two new components to the four present in normal sap. One of these contains the virus and shows as a tall, slim peak; the other, much smaller, appears only when the first is already large, and it consists of material serologically related to the virus but with little or no nucleic acid or infectivity. Some workers have found that the proteins of normal leaves decrease in amount as the virus increases, and others that they remain unchanged. To study the effect of infection and to see whether any change in the normal proteins is directly correlated with the virus content or with the severity of symptoms shown, we have examined the electrophoretic patterns of sap from plants infected with four viruses and grown under a range of conditions. Two of these viruses, potato Y and tobacco etch, accumulate to only a small fraction of the amount of TMV, and the first causes a less severe and the second a much more severe disease than tobacco mosaic. The third virus was a strain of potato X, which accumulates to about one-quarter the amount of TMV and causes a disease of approximately the same severity. Of the three other viruses only potato X introduced new components into the pattern; as with TMV, there was a tall, slim peak, although a striking difference is that this peak with virus X does not move in the electric field in pH 7 phosphate buffer; two small peaks given by components whose nature we have not determined are by analogy with TMV likely to be not infective and to lack nucleic acid. The patterns with sap from plants infected with virus Y or tobacco etch resembled those from uninfected plants, and the concentration of normal proteins was not decreased even by the etch virus which greatly crippled the plants. The concentration of the normal proteins varied with the age of plants and of leaves, and with their manuring. It was greater in young plants than old ones, and in young leaves than in old ones of the same plant, and was least in old leaves of plants deficient in nitrogen. Their concentration fell as leaves aged, but often fell no more in leaves where TMV was multiplying than in others. Sometimes there was considerably less in sap from infected than from uninfected leaves, but there was no correlation between the amount of TMV present and the amount of any normal protein. Most TMV and most normal protein occurred in leaves of plants receiving abundant nitrogen; in nitrogen-deficient plants the relatively small amount of virus produced was not at the expense of any electrophoretically detectable normal protein.

Extracts from upper leaves of tobacco plants could be examined directly in the electrophoresis apparatus after dialysis against pH 7 phosphate buffer. With extracts from lower leaves, however, this

method could not be used, as the patterns obtained were highly unstable, apparently because such leaves contain something that causes the normal proteins to aggregate. (Bawden and Kleczkowski.)

The antigenic components of preparations of tobacco mosaic virus

Ordinary precipitation tests with purified preparations of TMV and its antiserum do not suggest the presence of more than one antigenic component, but when made by the gel-diffusion method three components can be distinguished. One is the typical nucleoprotein, particles with weights equivalent to molecular weights of from 2–50,000,000, not all of which is infective. The other two seem to be identical with the so-called X-proteins that remain in the supernatant fluid when sap from infected plants is ultracentrifuged. These proteins are serologically related to the virus but lack some of its antigenic groups; they contain little or no nucleic acid, and usually have molecular weights of about 90,000 but they can aggregate into long, rod-shaped particles morphologically resembling the virus.

The X-proteins in purified preparations seem normally to be attached to virus particles, but some become detached when put into colloidal materials, such as agar gels or solutions of serum albumen. More is detached by incubating preparations with pH 8·8 borate buffer and still more by incubating at pH 10, but the virus particles then disintegrate and at least five other serologically distinguishable components are produced. (Kleczkowski.)

Electron microscopy

The objective-lens system of the electron microscope has now become so worn that it cannot be centred with an aperture in the objective lens. This has made impossible the continuation of thin-section work, and the decline in image contrast and resolution has also limited the scope and performance of the instrument in all other work.

Particle counting, which makes only modest demands on the microscope, has therefore been its main use, and an improved method for doing this was developed. Using this method, the multiplication of TMV in inoculated leaves has been studied, and particularly the changes immediately following inoculation. Preliminary tests showed that TMV rods extracted from recently inoculated leaves are damaged by dialysis against tap water. Dialysis against *M*/5-ammonium acetate has proved satisfactory, and counts give results closely paralleled by serological assays when the samples are prepared by grinding leaves, squeezing the sap through muslin, heating to 60° C. for 10 minutes, centrifuging at 8,000 g. for 10 minutes and then dialysing against *M*/5-ammonium acetate at room temperature.

The number of virus particles recovered from inoculated leaves sampled immediately after inoculation and washing depends on the concentration of the inoculum, and " Celite " increases the number to about the extent of increasing the concentration of inoculum by 100 times. When young leaves are inoculated, washed briefly in running water and then sampled at intervals, the particle counts

from successive samples decline rapidly to about 10 per cent of the initial value, and then rise more slowly. When older leaves are inoculated, the recovery of particles immediately after inoculation seems to be better than with young leaves, and the decline in concentration is less, and sometimes inapparent; the particle counts then remain more or less steady before they increase at the rate found with young leaves. When old leaves are detached from the plant immediately after inoculation and washing, and floated in water, the counts in successive samples go down, as with young leaves left on the plant; rods can be found in the water in numbers corresponding roughly to the difference between counts on extracts from washed, and washed and floated leaves. When purified TMV is rubbed over filter-paper and dried, rods can be recovered in much the same numbers from samples extracted with water up to at least 24 hours. Rubbing newly inoculated young leaves with *N*/10-NaOH or with 1 per cent "Teepol R" (Shell Chemicals Ltd.) did not significantly affect the number of rods found in samples taken soon after the second rubbing, but "Teepol R" decreased the concentration in samples taken 24 and 48 hours after the original inoculation.

These observations suggest that virus particles in the inoculum have three possible fates, distinguishable by the intensity of washing necessary to detach them:

1. They may immediately reach a state or site where they are unaffected by any washing.
2. They may reach a site where they are protected from a brief wash in running water, but not from the effects of a prolonged soaking.
3. They may remain on the surface of the leaf and be detachable by a brief rinse in running water.

Only particles of type 1 are likely to infect and multiply, and as these are most easily studied in leaves floated in water immediately after inoculation, most experiments were made with such detached leaves, which also seem to give less-variable results than leaves on the plants. The proportion of the rods found in the sample taken immediately following inoculation, which are of type 1, have been estimated by two methods, and it seems to be about 0·2 per cent at 25° C. and 5 per cent at 35° C.

The length and width of rod-shaped plant viruses show that narrow rods tend to be long and wide rods short, which is to be expected if the particles become increasingly brittle as they become wider. The scatter diagram of particles shows no obvious grouping of related viruses, and does not support the idea that there is a particular unique length for each virus, but rather that the length is determined mainly by mechanical considerations. (Nixon.)

The multiplication of viruses at 36°

The study of virus multiplication at 36° has more than academic interest because of the practical application of heat-therapy in producing virus-free lines of clonal varieties that are at present universally infected. It now seems that viruses do not fall neatly

into two types, one of which multiplies at high temperatures and the other not, but that strains of one virus may differ in their ability to multiply at 36°. We have previously reported that cucumber mosaic virus does not multiply at 36° and that healthy progeny can be obtained by keeping systemically infected plants at this temperature, but we have now confirmed that at least one strain of this virus will infect, and multiply in, plants kept at this temperature.

Similarly, the extent to which different strains of TMV accumulate in tobacco plants at 36° differs, and it also varies with the identity of the host plant. Our type strain accumulates much less at 36° than at 20°, particularly in the short days and low light intensity during the winter. An isolate obtained from infected plants kept at 36°, however, reaches higher concentrations in plants at 36° than at 20°. In *Nicotiana glutinosa* the type strain produces necrotic local lesions at 20° and chlorotic ones at 36° and the change to chlorosis is accompanied by virus accumulating in greater amounts, probably because many more cells now become invaded. Tomato aucuba mosaic virus, a strain that produces necrotic local lesions in tobacco leaves at 20° and chlorotic lesions at 36° shows a different effect. Despite the large chlorotic lesions at 36°, the virus increases so little that it does not reach an amount sufficient to be detected serologically; when such plants are put at 20° the virus increases rapidly, and within a day sap gives a precipitation endpoint of 1/16 with virus antiserum. (Kassanis.)

Tissue cultures

The line of King Edward potatoes reported last year as being freed from paracrinkle virus by culturing the stem meristem on agar was extensively propagated in the glasshouse and tested, and except for its failure to produce paracrinkle when grafted to Arran Victory plants, no significant difference was noted between it and the customary infected ones. There are now enough tubers for plants to be raised in the open next year so that its performance can be critically assessed. This year, again by excising the apical meristems from sprouts of tubers, which were cultured on agar before they were established, first as scions on tomato plants, and later as cuttings with their own roots, we have produced a line of Arran Victory plants free from potato virus S, which is present in all previously existing lines.

To assess the value of tissue cultures in work on the factors affecting virus multiplication, the amount of TMV present in tumorous tissue cultured in different conditions was compared with that in leaves of systemically infected plants. The protein content of extracts from tumours is less than that of leaf sap and so is the virus content, averaging about $\frac{1}{25}$ and apparently independent of whether or not the tissues are actively growing. Some additions to the medium increased the growth of the tissues but not their virus content, and others influenced virus content but not the growth of the tissues.

Although the tissues have no cuticle, they do not become infected by TMV unless they are wounded. Virus spread through inoculated tissue at a rate of about 1 mm. per week, of the same

order as the rate reported for spread through leaf parenchyma. No plasmodesmata could be detected in the tissues by methods that showed them clearly in leaf cells, and so the rôle previously attributed to plasmodesmata as the route for virus spreading from cell to cell seems a doubtful one. (Kassanis.)

Virus diseases of leguminous plants

Five distinct viruses were identified in leguminous plants of various kinds. One was broad-bean mottle virus, found in field beans at Cambridge, and which has only once been reported previously, in 1948, when it ruined a bean crop in the Midlands. Another, and this year the most prevalent in crops of field beans, was pea mosaic virus. A third, was a new record for this country, pea-leaf roll virus, which was found frequently in pea and field bean crops. It was first reported from Germany, Holland and Belgium in 1954 and 1955, where a disease previously thought to be caused by fungi was shown to be a virus disease. It appears to be widely distributed in the U.K., and when its effects were brought to the notice of growers they said they had long known plants in this condition. Samples taken from naturally infected plants at Rothamsted suggest that it halves the yield of field beans. It was transmitted, though only infrequently, between peas and field beans by *Macrosiphum pisi*.

The fourth was bean yellow mosaic virus, which also seems to be widely distributed and overlooked previously. It occurs in many strains of different virulence. An antiserum was prepared against a strain found infecting Gladiolus plants, and it proved most useful in distinguishing between this and the other viruses that are common in clovers, field beans and French beans. Although not prevalent in cultivated clovers, bean yellow mosaic virus is present in most of the clovers growing on waste land in and around Harpenden. It is common, too, in field beans, though infected plants usually are not greatly affected; some strains obtained from white clover, however, cripple field beans grown in the glasshouse.

The fifth was lucerne mosaic virus, which is very prevalent in lucerne more than two years old. The strain obtained from lucerne at Rothamsted, like one found in Northern Ireland infecting potatoes, does little harm to potato plants, and is transmitted through only a small proportion of tubers set by infected plants. Serological tests with antisera from America and Holland show that this is related to the American strains of lucerne mosaic that cause the serious disease, potato calico, characterized by severe leaf symptoms and necrosis of the tubers. (Tinsley.)

Viruses of cereals and grasses

In addition to barley yellow dwarf, whose occurrence in Britain we reported last year, three other viruses were distinguished in grasses and cereals during 1956. They were barley false stripe, a previously undescribed one that causes a disease we shall call streak mosaic of ryegrass, and one that causes a disease in wheat closely resembling striate mosaic.

Symptoms suggesting barley false stripe, sometimes called barley stripe mosaic, were seen in the variety Gloire du-Velay, growing in

Cambridge and raised from seed imported from France. Serological and other tests showed that these plants contained a virus related to barley false stripe, a seed-borne virus that is of considerable economic importance in Canada and the U.S.A.

Ryegrasses, both *Lolium perenne* L. and *L. multiflorum* Lam., were seen in many parts of England, Wales, Scotland and Holland with chlorotic streaks on their leaves and sometimes with leaves brown and necrotic. Mechanical inoculation of sap from such plants readily transmitted a virus to healthy ryegrass in the glasshouse. In thick stands of perennial ryegrass there is no obvious sign that the infected plants are much harmed, but with plants widely spaced the decrease in growth is striking. The virus was seen causing considerable damage to some crops of Italian ryegrass. Aphids, leafhoppers, thrips and Eriophyid mites were collected from naturally infected ryegrasses and transferred to healthy S22 IRG seedlings in the glasshouse. About one-sixth of the plants infested with mites developed symptoms of the streak mosaic, but all those infested with insects remained healthy. Further experiments with aphids, given widely differing feeding times on infected plants and test seedlings, failed to give any transmission. Suggestive evidence that the vector is smaller than aphids or leafhoppers was obtained by placing pots containing S22 seedlings, some covered with muslin and others uncovered, in a ley containing naturally infected plants. After 2 weeks in the ley, similar numbers of plants became infected in both the covered and uncovered pots. When 84 healthy seedlings were infested with 10 mites each, 5 developed streak mosaic. Dr. Keifer has identified three species of mites in our collection, and it is hoped to be able to identify the vector species certainly and, if it transmits readily, to do more exact experiments on the factors that affect its ability to transmit.

A disease of wheat closely resembling that caused by the leafhopper-transmitted striate mosaic virus, first recognized in 1950 infecting wheat in the U.S.A., was found to be caused by a virus transmitted by the Delphacid, *Delphacodes pellucida* (F.), which is common on grasses in the U.K. Insects do not transmit until 8–16 days after they first feed on infected plants, and they have remained able to do so for more than two months after ceasing to feed on infected plants. The initial symptoms appear 2–3 weeks after infection, and show as thread-like chlorotic spots and streaks; plants infected before they tiller are usually killed. In addition to wheat, barley, oats and perennial and Italian ryegrass were found to be susceptible.

We have made no survey to find the relative prevalence of the different virus diseases of cereals and grasses, but casual observations suggest that barley yellow dwarf is the most common. However, it is uncertain how prevalent this is, because the aphid *Rhopalosiphon padi*, which readily transmits from infected to healthy plants in the glasshouse, often failed to transmit anything from oat and barley plants showing what seemed typical symptoms in the field. The virus was transmitted from Bersee wheat infected artificially in the field as late as mid-August, and it was transmitted from Timothy grass found naturally infected at Aberystwyth and from perennial ryegrass at Harpenden. Preliminary tests suggest

that different grasses and different strains of grasses may differ in their susceptibility to infection, for it was transmitted in the glasshouse to some but not to all tested.

A field experiment to compare the losses caused by barley yellow dwarf in different varieties of wheat, oats and barley was complicated by excessive lodging in the wet August. Nevertheless, there were considerable differences in yield between infected and uninfected plants. Except with wheat, which suffered greater losses when infected between 14 and 19 May than when infected between 24 and 30 April, losses increased with earliness of infection. Losses were also correlated with the severity of leaf symptoms. In barley the losses were similar to those recorded in 1955, 25 per cent when infected early and 8 per cent when infected late. The losses in varieties of oats varied greatly, in some being less than in wheat or barley and in others more. (Slykhuis, Watson and Mulligan.)

The prevalence and importance of these virus diseases of grasses, as with those of clovers, have yet to be determined, but their existence immediately poses a question. Do any of the benefits derived from ploughing old pastures and reseeding come from the fact that virus-infected plants are thereby replaced by uninfected ones?

Viruses of cruciferous plants

Severely diseased turnip plants, which were first thought to be infected with a virulent strain of turnip crinkle virus, were found to contain the crinkle and what seems to be a previously undescribed virus. The new virus has spherical particles about the same size as those of crinkle virus, but the two are not related serologically, and they can be separated by differential precipitation with ammonium sulphate. This new virus has recently been found alone infecting turnips in Kincardineshire, near to the farm where the crinkle virus was first encountered. The host range and transmission by beetles of these viruses are being compared with those of turnip yellow mosaic virus, several strains of which, differentiated by the severity of symptoms they cause in Chinese cabbage, have been isolated from cruciferous plants growing in different localities. (Blencowe and Broadbent.)

We again co-operated with the National Institute of Agricultural Botany in trials to assess the relative susceptibility of cauliflower varieties to cauliflower mosaic, and operated fifteen insect traps in conjunction with a survey on this disease by the National Agricultural Advisory Service. *Myzus persicae* were exceptionally abundant in Kent during July, but not elsewhere, and few *Brevicoryne brassicae* were caught except in Devon and Kent during July and at Evesham in August. Of winged aphids bred on infected cauliflower plants, 18 per cent of *M. persicae* and 15 per cent *B. brassicae* transmitted cauliflower mosaic virus and 11 per cent of *M. persicae* and 3 per cent of *B. brassicae* transmitted cabbage black ringspot virus. (Broadbent and Heathcote.)

Further experiments confirmed that *M. persicae* is most effective as a vector of cabbage ringspot virus when it is first starved and then fed for only 2 minutes on infected plants, whereas cauliflower mosaic virus is transmitted only little more frequently by aphids given this treatment than by aphids allowed to feed for 24 hours on infected

plants. That the two viruses may be differently distributed in infected leaves was suggested by experiments with leaves irradiated with ultra-violet light, which again showed that this treatment almost prevents the transmission of the ringspot virus but has little effect on the transmission of cauliflower mosaic virus. Transmission from some leaves infected with the mosaic virus occurred much more readily than from others. Attempts to make an antiserum against this virus failed. (Mulligan.)

Potato viruses

Although as reported last year DDT was less effective in the hot summer of 1955 than previously in controlling aphids, the spray nevertheless checked the spread of potato virus diseases at Rothamsted. Two high-volume sprays decreased the incidence of leaf roll in the seed saved and planted in 1956 from 11·7 to 2·8, and eight sprays decreased it to 0·7 per cent: the incidence of virus Y was decreased from 11·5 to 7 and 5 per cent by the two and eight sprayings. At Lymington, too, spraying fortnightly with DDT decreased the incidence of leaf roll in plots containing initially 1 per cent infected plants from 19 to 2 per cent and of virus Y from 7 to 3 per cent. The stock of sprayed Ulster Prince now in its third year at Lymington had 0·1 per cent plants with virus Y and 1 per cent with leaf roll. The experiment at Harlow with King Edward was abandoned after four years because virus Y spread into the stock from other potato crops. Combined spraying and roguing maintained the health of the stock and cost less than buying new seed. The incidence of virus-infected plants was:

	LR Per Cent				Y			
	1953	1954	1955	1956	1953	1954	1955	1956
Unsprayed ...	0	4·1	26·6	—	0	0·05	0·3	—
DDT	0	3·7	4·4	4·5	0	0·05	0·7	13·2
Endrin	0	3·8	6·2	7·8	0	0·06	0·5	13·8
DDT + rogued	0	(3·7)	(1·6)	1·5	0	(0·05)	(0·5)	4·5
Endrin + rogued	0	(3·8)	(1·4)	2·9	0	(0·06)	(0·7)	9·1

The date-of-planting trial with the variety King Edward at Sutton Bonington was concluded. The percentages of infected tubers saved from 1955 were:

	Date of planting					
Time of lifting	14 Apr.	9 May	3 June	28 June	23 July	17 Aug.
LR:						
After 12 weeks ...	0	5·0	22·7	40·5	58·2	—
Lifted after haulm died	40·8	39·2	37·5	38·5	35·6	58·8
Y:						
After 12 weeks ...	0	2·3	3·7	14·4	10·0	—
Lifted after haulm died	12·4	15·0	11·2	14·4	15·2	7·9

As in the previous two years, (1) the healthiest stocks were those planted early and lifted after 12 weeks; (2) yield in 1956 from LR infected and healthy plants was greater from tubers lifted after haulm death than from those lifted early in 1955; (3) leaf-roll infection reduced yield by 76 per cent.

In an experiment at Rothamsted, done in co-operation with the Insecticides Department, DDT emulsion (2 lb. DDT per acre) was sprayed at low and high volumes, 4 and 6 times on 0·06-acre plots of S.S. Majestic, in which were planted 6 leaf roll and 6 virus Y infected tubers. Potato aphids were scarce during spring, but increased rapidly during July, leaving the crop during late July and early August. Aphid control was good, as the count on 150 leaves on 23 July shows :

	Total aphids	*M. persicae*
Unsprayed	2864	2700
HV × 4	12	11
HV × 6	12	7
LV × 4	8	2
LV × 6	24	23

Thirty-one other trials were made in various parts of England in co-operation with the National Agricultural Advisory Service. DDT was used in all, and in 3 this was compared with " Metasystox ". High- and low-volume application, with and without underleaf lances, was tested.

Eighteen insect traps were operated in unsprayed crops near to sprayed ones. *M. persicae* was scarce in May and June, but numerous in the Eastern Counties during late July and early August.

Two hundred and fifty tubers from a diseased stock of King Edward were subjected to the resorcin blue test for leaf roll and then planted. Leaf roll was correctly indicated in 66 per cent of the infected plants, but 42 per cent of those which reacted positively failed to show the disease; 6 per cent of the tubers which did not react produced infected plants. (Broadbent and Heathcote.)

Narcissus viruses

The trials at Rothamsted on the spread of viruses in Narcissus have been discontinued until the identity of the viruses present is better determined. Three types of symptom have been recorded, " severe stripe ", " mild stripe " and a faint mottle. Severe stripe spread little in 1953 or 1955, but more in 1954, when aphids were many times more numerous in spring than in the other years. Nevertheless, spread was slow : even in plots with 10 per cent of the plants initially infected, only another 16 per cent became infected during three years. When plots of healthy plants were bounded on 2 sides by 3 rows of infected bulbs, 6 ft. distant from the plots, only 7·6 per cent of the plants were infected.

Removing infected plants did not decrease spread, possibly because the plots were small and surrounded by others left unrogued. Spraying with DDT or " Mazidox " seemed to increase the incidence of stripe. (Broadbent and Heathcote.)

Sugar-beet virus diseases

A survey of the incidence of yellows in representative crops planted from commercial sugar-beet and mangold steckling-beds was organized with the help of the National Agricultural Advisory Service and sugar factory field staff; 87 per cent of sugar-beet and 46 per cent of mangold seed crops had less than 5 per cent plants

with yellows, and only 5 per cent of beet and 9 per cent of mangold crops had more than 20 per cent infected plants.

In the autumn of 1956, 135 sugar-beet steckling-beds had on average 0·12 per cent of plants with yellows, and only 2 beds were rejected because they had over 1 per cent. 344 mangold steckling-beds had an average of 0·46 per cent of infected plants, and 37 beds had more than 1 per cent.

Experiments and experience have shown that yellows can be controlled by raising stecklings under cover crops. An experimental sugar-beet seed crop raised under a barley cover crop contained no plants with yellows, so no effect from autumn insecticidal spray treatments could be assessed. Some of these stecklings were grown-on without transplanting; although they grew bigger, they did not lodge like the transplanted ones; were ready to harvest 2 weeks earlier, and were free from "second growth", which was common in lodged seed crops in 1956. Seed yields have not yet been determined. IPC and TCA sprays (done in conjunction with C. Parker, Norfolk Agricultural Station) in the autumn or in spring controlled weeds, especially volunteer barley from the cover crop and, without injuring the beet, greatly decreased the labour needed to clean the crop. This method of growing seed combines effective virus control with economies in labour and gives scope for mechanizing the cultivation of the crop. (Hull and Firth.)

The insecticidal effect of "Hanane" and "Metasystox" applied to the soil along the rows at drilling time was compared with "Metasystox" spraying started immediately after the seedlings emerged and 10 days later. Incidence of yellows will be assessed in the plants next June. Seedlings from "Hanane"-treated rows drilled on 10 August were still toxic to aphids in petri-dish tests on 19 September. On 12 October the "Hanane" plots had 1 aphid on 40 plants, compared with 17 on the unsprayed controls. "Metasystox" was less persistent. "Thimet" was as effective as "Hanane" but depressed germination. (Gates.)

Spraying experiments on root crops at eighteen centres tested an early spray with "Metasystox" (end May–mid-June), a late spray (2–3 weeks later) and both. Only at Ipswich did more than 5 per cent of plants show yellows on unsprayed plots by the end of September; here the late spray decreased the incidence of yellows more than the early, though neither was as effective as in previous years. Aphids presumably arrived later and over a longer period than usual, and the double spray was more effective than either single spray, whereas previously two sprays have been little better than one early. Spraying increased yield by 5–8 per cent.

At Sprowston both early and late sprays with "Metasystox" decreased the incidence of yellows. The late spray had less effect on plots already sprayed early. DDT had no effect on yellows incidence.

The simultaneous control of *Pegomyia betae* and spread of yellows by aphids was tested at Dunholme. *P. betae* was controlled best by "Dipterex" (a proprietary organo-phosphorus insecticide with low mammalian toxicity), almost as well by "Metasystox" and least, though still effectively, by DDT emulsion applied at the end of May. Spread of yellows from artificially infected plants was de-

creased most by " Metasystox ", not at all by " Dipterex " and the DDT plots had more infected plants than the unsprayed ones. A second " Metasystox " spray applied on 2 July decreased the number of plants infected by mid-September to less than a quarter. The early spraying halved the number of plants with yellows at this time, and the early and late spray together decreased them to a tenth. " Metasystox " sprayed at high volume was more effective than at low volume. (Blencowe, Firth, Gates and Hull.)

The testing of 150 inbred progenies selected for tolerance to yellows was continued. Some progenies, self-pollinated for a second time, had vigorous, green leaves free from necrosis when infected in the field. Yields are not yet known from this or another experiment to compare the yields of progenies with different foliage characters, when infected early and late with mild and virulent isolates of yellows virus. Plants inoculated in the field simultaneously with mild and virulent isolates were less stunted and yellow than when infected with either isolate alone. Field plants inoculated by aphids fed on glasshouse plants, which had earlier been inoculated with both isolates, developed very mild symptoms. (Hull.)

A plant of white campion (*Melandrium album*) showing ringspot and mosaic symptoms not previously recorded was found at Dunholme. The cause was readily transmitted to seedlings of white campion by sap inoculations using " Celite ", but not by *M. persicae*. Sap inoculations caused systemic infections in sugar beet, spinach and cowpea, a slight necrosis on rubbed leaves of thornapple, antirrhinum and pea, and no symptoms in tobacco, marrow, cucumber, carnation, lettuce, clover (*Melilotus* sp.) or runner bean. (Cornford.)

The work started in 1955 to assess the importance of wild beet as a source of pests and diseases for the sugar-beet crop was continued. It is apparent that wild beet is increasing in quantity in its old habitats and is appearing in new places on the British coasts and estuaries. On the East Coast it is one of the first plants to colonize the freshly disturbed soil of newly made sea-walls.

Seed collected from 80 individual *Beta maritima* plants in 20 localities was planted at Rothamsted. The plants grew well, and the form of the plants varied greatly. Seed from the East Coast generally gave larger and more upright plants than seed from the Atlantic Coast. Most seed lots produced plants of uniform type, but some from the East Coast gave mixed progeny, suggesting that the parent plant had been cross-pollinated with plants of different type. Occasional dark-red plants suggest that some of the cross pollination was with garden beet. A few samples were completely non-bolting, and a few plants bolted early enough to produce ripe seed during the first season's growth. Seed collected in and near the Ouse Outfall most resembled commercial beet, and this population may have arisen from commercial beet that has " gone wild " and not be true *Beta maritima*.

The plants from which seed was collected were labelled and revisited in the spring, to see whether they were perennial. All but a few labels had disappeared, and it was possible to see only that most of the groups of plants had survived or increased and not to decide on the survival of individual plants.

Wild beet continues to grow as a hedgerow weed in places where it established itself when the seed was washed inland by the tidal floods of 1953. In a few localities new seedlings were seen. Some of these hedgerow plants have sugar beet diseases, but less frequently than those growing on the foreshores and sea banks.

The ability of wild and commercial beet seed to germinate and grow in competition with the other plants of scrub grassland was tested at Rothamsted. Seed scattered in rough grass did not germinate; when the vegetation was removed to soil level and the seed raked in, a few seedlings appeared, but did not survive competition with the subsequent vigorous growth of grasses, briar and annual weeds. On plots where vegetation was first killed by sodium chloride applied at the rate of 8½ tons/acre, both wild and commercial beet seed germinated and grew, whether the seed was raked into bare soil or scattered among the dead vegetation. Observations will be continued to see how long these plants survive.

The distribution of diseases in 140 beet and mangold crops (about 2,000 acres) in the Shotley peninsula of Suffolk was studied in detail to see whether there was evidence of spread from the plentiful wild beet on the foreshore. All fields with more than 1 per cent of plants with beet mosaic or downy mildew (*Peronospora schachtii*) were within 1,000 yards of the foreshore. In some fields adjoining the foreshore nearly all the plants near the beach were infected with beet mosaic virus, and there was a steep gradient of infection, so that a hundred yards inland less than a tenth of the plants were infected. Beet yellows virus was generally more severe in this and the adjoining peninsulas than in much of the remainder of East Anglia, and was especially prevalent near the tip of the peninsula, where some fields were nearly 100 per cent infected by mid-August. A rough estimate suggests that losses from yellows infection on the 1,400 acres of sugar beet in this area were at least 2,800 tons of beet. One field, otherwise expected to yield 18 tons/acre, gave only 11 tons/acre.

In districts like this the effect of wild beet seems evident, and the following recommendations are made:

1. Farmers in such areas are more likely to profit from routine spraying of their sugar beet with a systemic insecticide than are growers in most other parts of the country.

2. Farmers might benefit if they decreased the growth of wild beet on their foreshores by spraying with 2, 4D or MCPA in the spring.

3. Wild beet should not be allowed to establish itself on the coast of north east Norfolk or on the banks of the rivers Ouse and Nene, because of the very large areas of sugar beet near by.

4. An attempt should be made to destroy the wild beet growing in the areas flooded in 1953, especially when commercial beet is to be grown in adjacent fields. (Blencowe.)

Changes in transmissibility by insects

The isolate of potato virus C found to become aphid-transmitted after ten years in *N. tabacum* sp. in the glasshouses has retained this ability while continually propagated in *N. glutinosa*: most lines

transmitted to Majestic potato plants lost this ability, and subsequent propagation for a year in *N. glutinosa* did not restore it. Similarly, strains of potato virus C obtained from Edgecote Purple potatoes have not become aphid-transmissible after a year or more in *N. glutinosa*. From *N. glutinosa* plants infected simultaneously with potato viruses C and Y, aphids have sometimes transmitted viruses that behave differently from either of these. Inoculated Majestic potatoes give black local lesions as with potato virus C, but they also become systemically infected, although these symptoms take longer to appear than those caused by virus Y. Isolations from such necrotic lesions in Majestic to *N. glutinosa* have sometimes given cultures difficult or impossible to transmit by *M. persicae*. (Watson.)

Another example of a virus apparently changing its ability to be transmitted by *M. persicae* was encountered in a strain of cucumber mosaic virus obtained about ten years ago from a naturally infected spinach plant. At that time and up till 1954 the virus was readily transmitted, under optimal conditions more than half the plants colonized with only one aphid became infected. Now other strains of cucumber mosaic virus maintained in the same manner and in the same glasshouses are still readily transmitted by *M. persicae*, but this one is not. It is transmissible by *Myzus ascolonicus*, though less readily than other strains. (Badami.)

Mycology

Potato blight

In further studies on the early phases of potato blight attacks, 300 tubers of each of 3 potato varieties were artificially infected in December 1955, and planted in April among a plot of healthy plants. Six of the Ulster Cromlech tubers, and 1 each of Majestic and King Edward, produced stem lesions, which originated below ground. The first 2 stem lesions were found on 12 June and others appeared at intervals up to 3 July. Sporangial infections near these plants were first found on 19 June and, of nearly 2,000 plants in the plot, 92 per cent were infected by 24 July. Blight was first found on commercial crops in the district on 1 August.

1956 was the last of a series of years in which we have tested, on the variety Majestic, the effects of applying two protective copper sprays and sulphuric acid for killing haulm. Spraying increased yield this year, when blight was severe, by 2 tons/acre; few tubers became infected in plots sprayed with copper. The sulphuric acid spray again did not affect the numbers of tubers infected, but by killing haulm and weeds it considerably facilitated lifting.

The proportion of infections caused by sporangia spreading between leaves touching or in water running off leaves was studied by exposing plants in pots to two different conditions. In one the plants were unprotected and were exposed to sporangia from all routes; in the second the potted plants were in a cage, which prevented contact with the leaves of crop plants, or spore-laden water dripping on the plant, but only very slightly obstructed the arrival of dry sporangia or those carried in splash droplets. Exposed for

24 hours, the protected plants developed 40 per cent as many infections as the unprotected plants. (Hirst and Stedman.)

Experiments on the nature of field resistance to potato blight were begun using the varieties Up-to-Date, King Edward, Majestic and Arran Viking. The growth of the 4 varieties was studied in plots arranged in a 4×4 Latin square. Majestic took a week longer than the others to emerge and to flower. Up-to-Date formed the densest canopy, and in mid-July the afternoon temperatures at ridge level averaged 2° F. lower in this variety than in plots of Majestic. Most varieties were severely damaged by gales in late July, and only King Edward remained erect.

A single Majestic plant with 7 infected leaflets was placed centrally in each of the 4 plots of 1 column of the Latin square for 1 week in mid-July. Spread occurred only once during this period, and lesions appeared on 42 King Edward plants, 32 Up-to-Date, 31 Majestic and 21 Arran Viking. As in glasshouse tests, the sporing zone on Arran Viking leaves was narrower than on leaves of the other varieties. The total number of spores produced per leaf decreased in the order Up-to-Date, King Edward, Majestic and Arran Viking, but on sporing areas the density of spores was similar with all varieties.

In the artificially inoculated plots, King Edward was 50 per cent defoliated 9 days before Arran Viking, and 5 days before in the uninoculated plots. This difference may be less than if each variety had been planted on its own as a crop; the small plots were all surrounded by guard areas of Majestic, which may have provided similar numbers of spores for all plots and so diminished differences between the 4 varieties. (Lapwood.)

Potato skin-spot

In another attempt to find whether skin-spots on tubers could be caused by isolates of *Oospora pustulans* from potato roots, 50 tubers of each of 6 varieties were dipped in spore suspensions 4 days after lifting, and then stored. In the spring 16 per cent of undipped tubers and 25 and 29 per cent of those inoculated with the isolates from roots and tubers had skin-spots. Many sprouts on tubers of all the varieties were infected, and it seems that infection of eyes or sprouts by *O. pustulans* is much more prevalent and important than the better-known skin-spot symptom. Eyes on growing tubers can become infected, and dormant eyes, cut from washed tubers soon after lifting, have produced conidiophores when incubated for 5 days at 18° C. in a humid atmosphere. Such conidiophores occurred on 30 per cent of the eyes of Majestic tubers grown at Rothamsted in 1956, and 90 per cent of the tubers carried the fungus either in eyes or on the stolon scar, although no skin-spots were visible. Similar infections occurred on Majestic grown in Yorkshire.

Tomato seedlings grown in pots of soil taken from several different fields at Rothamsted became infected with *O. pustulans*; one field had not grown potatoes for at least ten years.

At each of the six National Institute of Agricultural Botany centres, six maincrop varieties were examined in late August. As in 1955, the fungus was found everywhere causing brown lesions on the cortex of roots and stolons, and it varied in amount with

variety and locality. The disease rating in mid-August was correlated with the extent to which the seed tubers were infected at the time of planting. Mean disease ratings over the six centres of 56, 39 and 9 per cent were given to the roots of King Edward, Ulster Torch and Arran Viking, which had respectively 28 per cent seed tubers infected (13 per cent with skin-spot), 20 per cent with infected eyes (none with skin-spot) and no infection of eyes or skin-spot.

Of fungicides tested in a field experiment none showed promise of controlling the browning symptoms or increasing yield. The incidence and severity of symptoms on roots and stolons were decreased by applying a 10 per cent thiram dust to the seed tubers and in the furrow at 100 lb./acre, but not when either application was made separately.

In culture on both solid and liquid potato dextrose media the fungus grew better at 16° C., and there was little or no growth at 0° or 24° C. The dry weight of mycelium which grew in 14 days on 20 ml. of potato dextrose broth inoculated with a spore suspension was 18·5, 98·2, 101·6, 91·1 and 6·6 mg. at 4°, 12°, 16°, 20° and 24° C. respectively. The better growth of the fungus in low temperature may explain the fact that artificial inoculation of plants under glass in spring has produced severe browning and few, less severe lesions later in the year. (Salt.)

Apple scab

We have collaborated with the National Agricultural Advisory Service in observations on the correlation between outbreaks of apple scab and occurrence of the kind of weather thought to favour infection. We have also made observations on weather and spore concentration at Wisbech, Sudbury, Evesham and at East Malling. From each orchard, replicated dead leaf samples were taken in spring to estimate the relative number of ascospores they produced per unit area. Samples from Evesham and from one orchard at Wisbech gave few ascospores, but most others gave many. These differences were not necessarily associated with varieties or districts, for leaf samples from a series of Bramley's Seedling orchards in the Wisbech area differed by factors of 1,000 in their content of ascospores. These leaf samples alone give no certain guide to the spores caught by traps in orchards, for these catches depend also on the amount of leaf remaining per unit area of ground.

In the Wisbech area many growers successfully controlled scab by spraying when advised to from thermograph and dew-balance records. In conjunction with the Meteorological Office we have designed and tested a simplified dew balance to record how long surfaces remain wet, using as a test surface expanded plastic instead of an apple shoot. The new balance agreed with the older one to within about ± 1 hour, except during the earliest stages of dew formation. The differences between the two instruments are rarely greater than differences between leaves in different parts of the orchard.

Spraying the ground with 500 gal. of 0·1 per cent Sodium DNOC/acre in March again greatly decreased, by 92 per cent, the number of ascospores liberated from dead leaves.

A spore trap, operated among severely affected trees at Harpenden in July and August, caught more air-borne conidia on dry, sunny days than during wet weather. (Hirst and Stedman.)

Spore trapping

Preliminary experiments, with the main aim of devising suitable methods and apparatus for trapping spores from aeroplanes, were made in conjunction with the Meteorological Office and showed interesting changes in the number of spores trapped at various heights up to 10,000 feet.

Mushroom composts from beds suffering from the troublesome "Mat disease" were studied in the wind tunnel. At low wind speeds few of the ridged spores of the unidentified hyphomycete that forms the "mat" were dispersed, but as wind speeds were increased they came off in increasing numbers, and disturbing the dry compost dispersed them in quantity. Experiments are now to be made to see whether beds normally become infected by air-borne spores and, if so, at what stage of their development. (Hirst.)

The wind tunnel was also used to study the liberation of ascospores of *Ophiobolus graminis* from infected wheat stubble. Their liberation after wetting the stubble was confirmed, but attempts to measure the rate at which asci mature were inconclusive, probably because the stubble was collected too late. (Stedman.)

Pea wilt and foot rot

Field experiments on pea wilt, caused by *Fusarium oxysporum*, and foot rot of peas, caused by *Fusarium solani*, were continued at Rothamsted and on a wilt-sick field in Essex. Of nine English pea varieties tested in Essex, only Kelvedon Triumph and Harrison's Glory were wilt-resistant. Adding DBNP (2 : 4-dinitro-6-*sec*-butylphenol) herbicide to inoculated soil in pots in the glasshouse before planting peas decreased wilt by 70 per cent, but applications after peas had grown for 4 days in inoculated soil were ineffective. *Fusaria* growing on agar media were strongly inhibited by the herbicide. When DBNP was applied as a drench to wilt-sick soil in Essex before sowing, the onset of wilt was delayed. Later in the season, however, treated plots developed wilt as severe as that on untreated plots.

Only 8·6 per cent of all *F. oxysporum* isolates obtained by direct soil plating from wilt sick soil were pathogenic towards the pea variety Onward, and none was pathogenic towards varieties Alaska and Delwiche Commando, which are differential hosts for races 2 and 3 respectively. Over 80 per cent of the isolates from the roots of diseased Onward peas grown in infested soil infected Onward. Centrifuging water suspensions of soil and plating out the supernatant fluid increased the *Fusaria* isolated, and this technique may lead to a rapid test for showing whether or not particular fields are suitable for growing peas.

Field experiments at Rothamsted again showed that foot rot spread quicker than wilt and that each developed quicker alone than when soil was inoculated simultaneously with *F. oxysporum* and *F. solani*. Although seedling blight reappeared, very little wilt developed when soil was inoculated with *F. oxysporum* at

planting time. To test whether Rothamsted soil deters growth of *F. oxysporum*, the effects of aqueous extracts on spore germination were compared with extracts from 4 Essex soils, 2 wilt-sick and 2 wilt-free. After 12 days, only 5 per cent of the spores germinated in Rothamsted soil extract, 17 per cent in wilt-free soil extract and 61 per cent in wilt-sick soil extract. Comparable figures for *F. solani* were 4, 14 and 8 per cent respectively.

The rhizosphere populations and root exudates from pea varieties with different susceptibilities to 3 physiologic races of *F. oxysporum* f. *pisi* were further studied. The variety Onward, susceptible to race 1, had more fungi, bacteria and actinomycetes near its root surfaces than did either Alaska or Delwiche Commando, which resist race 1. Qualitative differences between rhizosphere populations of the 3 varieties were most apparent in *Fusaria* and bacteria, but *Mucorales*, *Trichoderma*, *Penicillium* spp. and *Gliocladium* were more abundant in the rhizospheres of plants resistant to race 1 than in the susceptible variety Onward. Rhizosphere populations changed both quantitatively and qualitatively as plants aged, and they were usually maximal after 14 days. The germination of spores of the 3 races of the fungus were differently affected by water extracts of the 3 rhizosphere soils. Spores of a race able to wilt a given variety germinated well in rhizosphere soil extract from that variety, and germination was less in extracts from the rhizosphere of a resistant variety.

When soils in which each of the 3 pea varieties had grown were inoculated with spores of race 1 and planted 48 hours later with seedlings of the susceptible variety Onward, plants became severely wilted in pots in which Onward had previously grown. Wilting was much less, and developed more slowly, in pots previously cropped with the resistant varieties Alaska and Delwiche Commando. As Onward peas wilted in fresh soil inoculated with race 1, it seems that roots of resistant varieties either secrete substances that prevent race 1 spores from germinating or stimulate a soil microflora with this effect. (Buxton.)

New records of diseases

Melon wilt, caused by *Fusarium oxysporum* f. *melonis*, was identified in a commercial garden at Chorley Wood, Herts, during August, where it killed about 70 per cent of plants of *Cucumis melo* var. *cantaloupa* variety Tiger.

Lucerne wilt, not recognizable as the well-known Verticillium wilt, was first seen on 2 July at Rayne, Essex, where diseased plants occurred along the edge of a patch of wilted peas. Of 17 cultures of *Fusarium oxysporum* isolated from pieces of discoloured stem vascular tract, 4 wilted Onward peas, an exception to the high degree of specificity usually found in *F. oxysporum*. At Rothamsted a similar disease was seen in August among lucerne in the ley–arable experiments on Highfield and on Fosters. Again *F. oxysporum* was isolated from the discoloured vascular tracts, but *Verticillium* sp. also grew from diseased stems kept in a damp atmosphere. Wilt symptoms are appearing in pots of lucerne inoculated with the Fusarium. (Buxton.)

Cereal diseases

Dry weather in May checked eyespot, *Cercosporella herpotrichoides*, on late-sown wheat in which the fungus had not already penetrated deeply, but the cold, wet summer favoured its later development and gave an unusually high proportion of straws with slight lesions at harvest. On Broadbalk, sown in November, the proportion of infected straws was as usual lower in the first than in the second, third or fourth crop after fallow. Mean values for 8 plots after fallow were 9 per cent straws with severe lesions, and 22 per cent with slight, compared with the average for the preceding 18 years of 21 per cent severe and 19 per cent slight. Plots after wheat averaged 27 per cent severe and 24 per cent slight, compared with the 18-year average of 45 per cent severe and 22 per cent slight. About 26 per cent of the total area was lodged, and much was untidily straggled; both effects were associated with eyespot.

In the four-course rotation experiment, wheat sown in mid-October had 54 per cent straws with severe and 23 per cent with slight lesions, almost doubling the previous average. Substituting beans for ryegrass before wheat did not decrease the incidence of eyespot, which in spring killed many plants. Spring-sown barley which preceded beans in this experiment had the unusually high proportion of 19 per cent straws infected, mostly too slight to do direct harm but enough to maintain the fungus in dangerous amounts for later wheat crops. In the six-course rotation experiment eyespot was about average on wheat, but there were more lesions than usual on barley and rye. (Glynne.)

Take-all caused by *Ophiobolus graminis* was very severe on the sixth successive wheat crop in an experiment on this disease, and was more severe on spring- than on autumn-sown Atle. One year free from susceptible crops on our farm usually decreases this fungus to negligible amounts, but in this wet year whiteheads occurred where wheat alternated with potatoes.

Take-all was negligible on Broadbalk after fallow, and although it occurred on other parts of the field, it was less than in some other fields at Rothamsted. On plots 13 and 14 for the second year in succession take-all was more severe on the heavily limed than on the lightly limed parts.

Gibellina cerealis occurred again on the alternate wheat and fallow experiment on Hoos field, its only known habitat in Britain. (Glynne and Cock.)

In the third and last year of an experiment at Rothamsted, in which 2 varieties of winter wheat followed 2 years under various crops, the first, second and third successive crops of Holdfast wheat yielded 34·8, 23·7 and 18·8 cwt./acre and Cappelle 49·6, 35·8 and 22·5 cwt./acre, with an average of 23, 18 and 16 ears per linear foot of row. The large differences in yield and ear number after different crops were closely associated with difference in incidence of eyespot, take-all and weeds. Despite an exceptionally difficult harvest, contrasting with the excellent conditions in 1955, yields on land that carried no cereals in the two previous years averaged only 6 cwt./acre less than in 1955; the best plot of Cappelle gave 56½ cwt./acre, 10 cwt./acre less than in 1955.

This experiment is one in a series which has shown that responses of wheat to various agricultural treatments depend partly on the incidence of eyespot and take-all, and that the responses need to be measured on land free from and infested with these diseases. Early sowing has given the best yields on uninfested land, but eyespot, which is most damaging on early-sown crops, can counteract this effect. A preliminary experiment, on rich, uninfested land, heavily dressed with nitrogen, was made to measure the effects of varying the date and rate when Cappelle wheat was sown. Mean yield of 9 plots sown 27 September was 61½ cwt./acre, and from successive sowings at 3-weekly intervals 58, 50 and 41 cwt./acre. Much smaller differences depended on seed rate and nitrogen; 3 bushels of seed yielded more than 1½ or 4½ bushels/acre, the largest effect amounting to 3½ cwt./acre of grain; 6 cwt./acre of sulphate of ammonia applied in spring gave slightly higher mean yields than did 3 or 9 cwt./acre; the largest increase from nitrogen amounted to only 1½ cwt./acre. (Glynne and Slope.)

In the ley–arable rotation experiment at Rothamsted eyespot has always been more prevalent in wheat following arable crops than after ley, and in 1954 and 1955 its incidence was so high that it decreased yields. Barley, which is susceptible to eyespot, and which preceded wheat in the arable sequence, was therefore replaced by oats, a much more resistant crop. The wheat crop in 1956, following oats, had only 0·2 per cent of the straws with eyespot lesions on both Fosters and Highfield, and for the first time since the experiment began the incidence of eyespot was the same in the ley and arable treatments.

The incidence and severity of take-all increased in each successive crop when winter wheat was grown at Woburn for 3 years; weeds, especially *Agrostis gigantea*, also increased. The severity of take-all was not decreased by nitrogen or thin sowing, as it was in previous experiments at Rothamsted, possibly because the intense weed competition limited root growth. Eyespot was much less prevalent in 1956 than in 1955, and was enough to cause damage only in plots of Holdfast which received 6 cwt./acre " Nitro-Chalk " in March. Grain yields averaged only 10·3 cwt./acre compared with 14·6 in 1955 and 27·4 in 1954 when the crop was much cleaner. For the third successive year 6 cwt./acre " Nitro-Chalk " applied in April yielded most grain, it averaged 18·7 cwt./acre compared with 5·3, 14·8 and 12·9 cwt./acre respectively for no nitrogen, an application in March, and one divided equally between March and May. The fertilizer applied in May, which strikingly increased weed growth as well as take-all, had little effect on yield, which averaged 5·9 cwt./acre. The two seed rates yielded the same weight of grain in nitrogen-deficient plots, but thin sowing yielded 29 per cent less than thick sowing, where 6 cwt./acre of " Nitro-Chalk " were applied. (Salt.)

Club-root of cruciferous plants

The main work, done in conjunction with F. T. Last of the Insecticides and Fungicides Department, was to study the action of the systemic fungicide, griseofulvin, on club-root, particularly to establish whether it could suppress or retard the disease when

applied only as a spray to the leaves. Last year we found that griseofulvin decreased club-root almost as well when sprayed on to plants as when added to the soil, but then no strict precautions were taken to prevent the spray from reaching the soil. This year great care was taken to ensure that the spray could not reach the soil, and it seems that, when this is done, griseofulvin applied to the leaves has little or no effect on the development of clubs. The earlier results are now attributed to spray falling on the soil or running down the stems, so that it could have inhibited *Plasmodiophora brassicae* in the soil or have been taken up by the roots and inhibited the pathogen within the host.

As effects of griseofulvin were being assessed by weighing tops and roots, it seemed opportune to make some observations on the effects of *P. brassicae* on the growth of its host plant. No such study appears to have been made before. Two growth analyses were made by taking samples frequently, from the time of planting and inoculating, until the clubs eventually began to decay. Measurements were made principally of the dry weights of various organs and of leaf area. The many data obtained are still being analysed, but the main effects of *P. brassicae* on cabbage seem to be as follows:

The most important (if also the expected) consequence of infection is to alter the distribution of dry weight in the plant. No changes in dry weight, or indeed, in any other quantity, were detected until there were visibly clubbed roots, and differences between healthy and diseased plants began when the gall was initiated, and they increased as the gall grew.

Compared with healthy plants, the root system of diseased plants constituted a greater proportion of the total dry weight, and this proportion increased with time. After clubs appeared, i.e., about three to four weeks after inoculation, there was very little further increase in the weight of fibrous root, and increase in root weight was nearly all from growth of the clubroot gall. With this diversion of an increasing proportion of the dry weight to the root, the weight and rate of growth of tops correspondingly decreased.

Changes in the assimilating system were considered in terms of leaf area and net assimilation rate. Increase in total leaf area closely paralleled that of total dry weight: it was slower than in healthy plants and attained a lower limit. The rate of production of expanded leaves was lowered immediately clubs began to grow. There were fewer leaves on diseased plants, but a decrease in the mean area of leaves contributed equally to the decrease in total leaf area. Leaves of diseased plants failed to attain either the area or thickness of leaves in corresponding positions on healthy plants.

There was a suggestion that net assimilation rate was slightly lowered by infection. One factor which might have affected this was the frequent wilting of leaves of diseased plants, caused by the fibrous root system failing to develop when clubs were formed. There were no effects on the succulence of the shoot as measured by water content per unit dry weight.

Inoculating later, or with fewer spores, delayed growth of clubs and the consequent interference with growth of fibrous roots and tops. A larger plant then grew before clubs developed, but this larger plant later produced a much larger club than could form on a

plant inoculated early. Clubs produced on cabbage by different isolates of *P. brassicae* varied in form and in their rate of growth.

It has been previously reported that the proportion of spores which germinates depends on their source. Germination is also affected by the treatment of the sample during storage, and by secretions of the roots of host plants. When spores were stored (at 4° C.) in dilute suspension their capacity to germinate and to infect was sometimes decreased, suggesting that a factor necessary for germination can be leached from the spores. Germination was hastened, and the proportion of spores that germinated was increased by the presence of host plants or by incubation in diffusates from roots of host plants. (Macfarlane.)

Sugar-beet diseases

A spray containing 1 per cent streptomycin and 1 per cent glycerol effectively controlled downy mildew (*Peronospora schachtii*) on sugar-beet seedlings in the glasshouse. In a preliminary study of the incidence of oospores in infected leaves from Lincolnshire and Norfolk in September and October, oospores were found in 35 out of 193 leaves.

The hypocotyls of sugar-beet seedlings were found to be more susceptible to damage by ultra-violet rays than the seedling leaves, or the leaves of fully grown field plants. The hypocotyl injury resembled the early stages of strangles, the cause of which is not known. (Cornford.)

Insecticidal seed dusts containing gamma-benzene hexachloride gave an increase in seedling emergence from seed sown in July and in the field at Dunholme. After singling, however, toxic effects from the gamma-BHC caused loss of plants, distortion and stunting of the foliage and death of the tap root. The injury was greatest on natural seed of a polyploid variety and was worse on natural seed of a diploid variety than on rubbed seed, and was greater with increased dosage of seed dressing and with high seeding rates. The percentages of surviving plants with damaged tap roots for half, normal and double the recommended dosage were 0·5, 10 and 43 for natural diploid seed; 2, 3 and 31 for rubbed seed and 8, 38 and 67 for natural polyploid seed. (Hull.)

In a series of experiments arranged in co-operation with Sugar Corporation fieldmen, seed soaked in ethyl mercury phosphate solution gave an average of 10–20 per cent more seedlings from 4 different seed batches. In three years this treatment has given an extra 10 per cent seedlings under good emergence conditions and 20–30 per cent more under adverse conditions, and has increased plant stand by 1·8–5·8 per cent. In small-scale trials benefits similar to those from ethyl mercury phosphate were given by "Aretan" or "Abavit S" (0·5 per cent formulated material) steeps. Where soil fungicides were applied along rows sown with seed treated with ethyl mercury phosphate, emergence was increased by 3·5 per cent. (Gates.)

Several fungi were isolated from roots of plants suffering from "Docking disorder". Of 8 species inoculated to sugar-beet seedlings in pots of John Innes compost adjusted to three pH levels, 5·3, 6·5 and 8·0, only *Fusarium oxysporum* and a *Pythium* sp. caused

damage. Symptoms were more pronounced in acid soil than in alkaline. Affected plants were shorter than controls and had inwardly-rolled somewhat chlorotic leaves. Roots were not fanged, but 19 per cent were twisted and forked in plants inoculated with *F. oxysporum*, 21 per cent in those with *Pythium* and 5 per cent in uninoculated controls. Profuse lateral root production was also characteristic of plants inoculated with these two fungi. It seems that, although *F. oxysporum* and *Pythium* can damage sugar beet, there are probably additional causes for root fanginess. (Buxton.)

Disease survey of experimental crops

Lucerne wilt. During hot, dry weather in early September extensive wilting occurred on second- and third-year plots on the Highfield Ley–Arable Experiment and on the third-year plots of the Fosters Ley–Arable Experiment. On 4 October the percentage area wilted on first-, second- and third-year plots was 0, 17, 45 on Highfield and 0, 0, 22 on Fosters. The vascular tissues of root and stem of wilted plants were stained brown, and from this tissue a *Fusarium* sp. and a *Verticillium* sp. were isolated.

Crown wart of lucerne (Urophlyctis alfalfae). This disease was prevalent on the third-year lucerne plots of the Woburn Ley–Arable Experiment, but only when the previous rotational sequence contained lucerne. The disease did not occur on any of the first- or second-year lucerne plots. Infected plants were vigorous and seemed to be suffering little loss of yield.

Chocolate spot of beans (Botrytis cinerea). This disease was more prevalent than usual on both winter- and spring-sown beans, but the aggressive stage (coalescence of spots) did not occur until mid-July, and losses of yield were not very great. In an experiment comparing winter- and spring-sown beans at different levels of potash and phosphate fertilizer, there were considerable differences in the incidence of chocolate spot on different plots. On 9 August an estimate was made, but the only treatment difference was that winter-sown beans were more heavily infected than spring-sown; there was no consistent effect of potash or phosphate fertilizer. However, the disease was well advanced when the estimate was made, and there may have been differences earlier.

Rust of beans (Uromyces fabae). This disease was unusually widespread at Rothamsted during August and September, but too late to affect yield greatly.

Clover rot (Sclerotinia trifoliorum). The clover in the Six-course Experiment at Rothamsted was very badly infected by *Sclerotinia* in the winter and spring, and many plants were killed. The surviving plants were too few to cover the ground in the summer, and the crop was further weakened by an infestation of larvae of the pea and bean weevil in June. All the lucerne crops on the farms had a few plants killed by *Sclerotinia*. (Slope.)

NEMATOLOGY DEPARTMENT

F. G. W. Jones

F. G. W. Jones succeeded B. G. Peters as head of the Nematology Department on 1 January 1956, and H. R. Wallace joined the staff on the same date. D. W. Fenwick spent three months in Trinidad studying red ring disease of coconut palms. The department helped to organize a fortnight's intensive course in Nematology for members of the National Agricultural Advisory Service and of Universities held at the Provincial Headquarters of the National Agricultural Advisory Service in Bristol. Six members of the staff attended for various periods and gave lectures and practical demonstrations. In the Michaelmas Term, F. G. W. Jones gave a course in Plant Nematology at Cambridge University. During the year numbers of visitors have been taught the basic concepts of nematology. This relatively great expenditure of time on teaching arises from the absence of interest in plant nematology at most Universities.

F. G. W. Jones has acted as advisory editor to the new journal *Nematologica* and as British representative of the Society of European Nematologists. D. W. Fenwick, H. R. Wallace and J. J. Hesling gave short talks at the British Association meeting in Sheffield.

The following visitors worked in the department during the year : Mr. J. W. Meagher, Plant Research Laboratories, Victoria, Australia (to 9 March); Mr. A. G. Whitehead, holder of a Colonial Service Studentship (to 27 July); Mr. H. E. Welch, Department of Agriculture, Entomology Laboratory, Belleville, Ontario, Canada (to 7 December); Mr. R. C. Anderson, Ontario Research Foundation, Canada (from 22 October); Mr. C. Logan, Empire Cotton Growing Corporation, Kampala, Uganda (30 July–10 August); Mr. B. Sripathi Rao, Rubber Research Institute, Kuala Lumpur, Malaya (23 July–3 August) and Mr. C. O. R. Everard, Regent Street Polytechnic, London (3–15 December). Other visitors included Dr. H. Goffart, Biologische Bundesanstalt, Münster, Germany, and Dr. J. W. Seinhorst, Instituut voor Plantenziektenkundige Onderzoek, Wageningen, Holland.

The revised edition of the late T. Goodey's *Nematode Parasites of Plants Catalogued Under their Hosts*, completed by J. B. Goodey and Mary T. Franklin, has now been published. The Ministry of Agriculture technical bulletin on *Laboratory Methods for Use with Plant and Soil Nematodes*, also by the late T. Goodey, has been revised by J. B. Goodey and is now published. A Ministry of Agriculture bulletin on *Sugar Beet Pests*, by F. G. W. Jones, is also in the press.

During the year many specimens for identification and many inquiries have been received from home and abroad.

Non-cyst-forming and Other Soil Nematodes

Work has continued on the relationships to mushroom mycelium of various nematodes, particularly *Aphelenchoides* sp. and *Paraphelenchus* sp. When cultures are inoculated with small numbers of *Aphelenchoides* the population increases to a high level and the mushroom mycelium gradually disappears. Ultimately the *Aphelenchoides* population declines and is replaced by saprobic nematodes which increase greatly in numbers. Nematodes are an important factor in the production of mushrooms commercially, and may be controlled by peak heating of compost and the exercise of care and adequate hygienic measures in the beds.

A comparison has been made of the rates of population increase of *Ditylenchus dipsaci* on a susceptible and a resistant variety of oats. Seedlings were grown in pots and on paper pads and inoculated with the eelworms. Samples of seedlings were taken at standard intervals and the nematodes within their tissues counted either by a staining method or after maceration in a blender. Population increase is rapid in the susceptible variety and almost non-existent in the resistant variety, although invasion is heavy.

In a recent report from Italy wheat was said to be attacked by *D. dipsaci*, but the symptoms described resembled those caused by *Anguina tritici*. Italian wheats have been grown in pots inoculated with either *D. dipsaci* or *A. tritici*. In no case was there a subsequent attack by *D. dipsaci*, whereas symptoms and ultimately galls developed on the plants exposed to *A. tritici*. (J. B. Goodey and D. J. Hooper.)

A new species of *Hoplolaimus*, found associated with the roots of the oil palm *Elaeis Guineensis*, has been described, after making a detailed examination by serial sections of the structures, particularly the telamon, in the male tail.

Revision of the late T. Goodey's *Soil and Freshwater Nematodes* is proceeding slowly. (J. B. Goodey.)

Several populations of *Aphelenchoides* nearly related to *A. parietinus* have been obtained from mushroom compost and decaying plant material. Attempts have been made to culture these on fungus on agar plates, and four populations have been established. Morphological comparisons have shown that at least two morphologically distinguishable species occur which will not interbreed and have not been described in the literature. Data for their description are being assembled. Some of the known plant-parasitic *Aphelenchoides* have been tried in cultures to discover whether they are obligate parasites on higher plants, but only one, *A. fragariae*, was found to thrive on fungus. (Mary T. Franklin.)

D. W. Fenwick spent three months in Trinidad at the request of the Colonial Office, studying red ring disease of coconut palm. He confirmed that the disease was caused by the nematode *Aphelenchoides cocophilus*, but little evidence was obtained in support of the view that the palm weevil *Rhyncophora palmarum* acted as a vector. Examination of trees indicated that red ring started at the base of the trunk and extended upwards to the growing point, giving rise to the cylinder of red tissue characteristic of the disease. The occurrence of the worm in the roots of trees showing very slight

symptoms suggested that worms entered the base of the tree from the roots. The presence of the nematode in soil suggested that the disease was soil-borne, and this conclusion was confirmed by the patchy distribution of Red Ring within plantations. In two cases nematodes were recovered from the husk of dropped seed nuts, suggesting that spread might occur by this means to new plantations. A report on this visit, with recommendations for further work, has been prepared and forwarded to the Colonial Office.

Greenhouse tests with numerous populations of *Meloidogyne* have been continued. Knowledge of the host ranges and morphology of the known species has been extended by some of the tests, and others have been for the purpose of identifying populations received for diagnosis. A slide collection of various stages of the different species is being formed. (Mary T. Franklin and A. Rae Forster.)

Cyst-forming Nematodes of the Genus *Heterodera*

Potato-root eelworm (Heterodera rostochiensis *Woll.*)

A survey of the soil populations of cyst-forming nematodes in experimental sites at Rothamsted and Woburn has begun. Most of the land at Woburn carries potato-root eelworm and, on some experiments, the infestation is sufficiently high to complicate the results of potato yields. The low level of accuracy obtained in this sampling has underlined the necessity for further investigations into the errors attendant on soil sampling, and a study of the source of these errors has begun. (D. W. Fenwick, Elizabeth Widdowson and Joan M. W. Hurrell.)

Experiments on hatching from free eggs of *H. rostochiensis* show that, although the general relationships are similar to those for the hatching of larvae from eggs within cysts, it is doubtful whether the technique is as useful for assay purposes as the cyst-hatching method. (D. W. Fenwick and Elizabeth Widdowson.)

A single-cyst hatching experiment has been conducted to test earlier results, which suggested that the percentage hatch was small from large, full cysts and to explore methods of reducing variability in hatching experiments. (J. J. Hesling.)

Joint work on the chemical nature of the hatching factor produced by potato roots with Professor Sir A. R. Todd of Cambridge and Professor R. H. Stoughton of Reading has ceased, but work is continuing in conjunction with the Biochemistry Department. Progress on the chemical aspects of the problem has been made by G. H. Wiltshire. Numerous chemical fractions have been bio-assayed, and large quantities of potato-root diffusate for the work have been produced from potted plants. An attempt has also been made to produce diffusate hydroponically in jars of 1 litre capacity to avoid impurities from soil. Experiments using water and nutrient solutions have shown that diffusate can be produced under these conditions but does not exceed in concentration that produced in pots. Further experiments are in progress to determine the conditions under which rapid root growth can be encouraged and maintained. Attempts are being made to culture roots and infect

them with sterile larvae of potato-root eelworm. (D. W. Fenwick and Elizabeth Widdowson.)

As a preliminary to work on nematicides, a study of the effects of pure ethylene dibromide upon larval emergence from cysts has begun in order to test the relationship between kill and hatchability. (D. W. Fenwick.)

The six-year co-operative experiment run jointly with the Shell Chemical Co. Ltd. and the West Norfolk Fertilizers Ltd., in which the long-term effects of crop rotation and soil injection with " DD Mixture " were being investigated, terminates at the end of the year. Potato yields show few outstanding increases over those obtained at the start of the experiment. The " DD Mixture " injections have noticeably reduced the growth of weeds. Analysis of the yield and eelworm population figures is in progress. (J. J. Hesling and C. C. Doncaster.)

Resistant crosses of *Solanum andigenum* and *Solanum tuberosum* have been tested against a number of potato eelworm populations obtained from various localities. The existence of resistance-breaking biotypes of the eelworm first noted by Scottish plant breeders has been confirmed, such biotypes having been obtained from Lancashire, Lincolnshire, Kent, Devon and Jersey. Estimates of the proportion of resistance-breaking biotypes in a number of populations have been obtained. (F. G. W. Jones.)

Cereal-root eelworm (Heterodera major *O. Schm.*)

The long-term experiment at Stoke-on-Tern on the build-up of soil populations of the cereal-root eelworm has continued, and the latest population counts show marked differences between the treatments (cereal species, fertilizer, time of sowing). The eelworm population under the oats rose to such a level that in 1956 the oats were a failure. Near Winchester, annual sampling for *H. major* on fields whose cropping plan is dictated by the farmer provided more evidence of the eelworm's behaviour under field conditions. Pot experiments on the population increase of *H. major* under oats, wheat and barley showed that this was greatest under oats, followed by barley and wheat. Plant-height measurements indicated that wheat was more susceptible to eelworm attack than barley. Increase was greatest from low infestation levels; the proportion of large cysts in the total cysts produced fell with increase of inoculation rate.

The efficiency as hosts of *H. major* of four species of common ley grasses has been determined using a series of infestation levels. All these grasses proved to be poor hosts compared with oats; perennial and Italian ryegrasses and cocksfoot were only one-tenth as efficient hosts as oats. Timothy appears to produce no new cysts. Invasion of grass roots by *H. major* larvae is much less than that of cereal roots and, in the range of infestations used in testing the above grasses, there was no evidence of the inverse relationship between population build-up and inoculum level.

The rate of decline of cereal-root eelworm population in pots of fallow soil was investigated. There was little fall in population during the period August 1955–March 1956, but the population fell steadily between March and July 1956.

Root diffusates from eight species of cereals and grasses did not stimulate the larvae of *H. major* to hatch from cysts.

Further attempts to discover varieties of barley resistant to *H. major* have continued, and a variety testing technique has been tried out. (J. J. Hesling.)

Beet eelworm (Heterodera schachtii *Schm.*)

The influence of soil moisture on movement of larvae of the beet eelworm has been studied from two aspects : the indirect influence of soil moisture through the agency of the host plant and the direct effect of soil moisture on larval activity.

There appears to be an optimum moisture content for beet-root diffusate production which may coincide with optimum conditions for plant growth. It is generally assumed that the root diffusate attracts larvae to the roots, and the properties of diffusate as an attractant are being studied. Attempts are also being made to measure the rate of diffusion of beet-root diffusate in sand at different moisture contents.

The numbers of larvae invading cress seedlings in sand at different moisture contents show that there is an optimum moisture content for invasion which coincides with the optimum conditions for larval emergence from the cysts. Larval movement through sand is greatly inhibited if particle size is reduced to about 50 μ diameter or less. There appears to be a limiting pressure deficiency of the order of 200–300 cm. of water for larval emergence from the cyst and for movement in the soil.

Galactinol, inositol and glutamic acid are claimed by some American workers to be the major constituents of the exudates from beet roots. Bioassays show, however, that they have no significant stimulatory properties; the actual active factor is still unknown. Larval emergence in sugars suggests that the beet eelworm used in the experiments consisted of two distinct populations with different optimum concentrations for emergence. (H. R. Wallace.)

In the field, difficulties are experienced in measuring the rate of increase of soil populations from low levels and in assessing their effects upon yield. For these reasons, an experiment was made using large pots holding 10 kg. of sterilized soil to which numbers of cysts of known average egg content were added in a logarithmic series and in which single sugar-beet plants were grown. The lowest population level was equivalent to 0·0001 cysts/g. (0·003 eggs/g.) of soil and gave a yield of roots and tops significantly higher than the control pots to which no cysts were added, suggesting that small numbers of nematodes have a stimulatory effect. Apart from this there was a significant linear regression of yield upon log initial eelworm population. These results agree with those of previous pot experiments on *Heterodera rostochiensis*, *H. cruciferae* and *H. tabacum* (1954 Report). (F. G. W. Jones.)

Cabbage-root eelworm (Heterodera cruciferae *Franklin*)

Further details of morphology and development of juvenile stages of the cabbage eelworm have been obtained from examinations of whole mounts and microtome sections. Various embedding

media and methods of dehydration have been tried, including paraffin wax/ceresin mixtures, double embedding with celloidin and paraffin wax, embedding in Nonex 63 (the water-soluble monostearate of polyethylene glycol 1,000), and attempts are now being made, with assistance from H. L. Nixon, to embed and section in butyl methacrylate. Two types of simple differentiator tubes have been made and used with success for gradual transference of specimens from one reagent to the next in the course of dehydration and clearing.

A plot experiment was set up in mid-May to determine the number of generations of *H. cruciferae* per year. Winter rape has been sown at fortnightly intervals, and plants have been examined weekly from the time of germination to the first appearance of first-stage larvae within the eggs of the *H. cruciferae* which have developed on the roots. The second generation was completed by 1 October, each complete cycle taking about 10 weeks up to that time. (C. C. Doncaster.)

Predators of the Heteroderidae

Using a funnel-type soil fauna extractor and culture chambers, designed by P. W. Murphy, four common species of Collembola have been found to be predatory on cysts of *H. cruciferae*. One of these, *Onychiurus armatus*, which is probably the most important predator as well as the most abundant of the four species, also fed on cysts of *H. schachtii* and of *H. schachtii* var. *trifolii*, at least one *Dorylaimus* species and one *Mononchus*.

A rough estimate of the number of cysts damaged was attempted from a pot culture of *H. cruciferae*. Out of a total of 1,216 cysts recovered, 84 (6·9 per cent) showed characteristic collembolan damage, while a further 89 (7·4 per cent) showed damage of uncertain origin, possibly due to Collembola. A total of 251 *Onychiurus armatus* was recovered from the same soil sample; one to about every five cysts. As the remains of damaged cysts may be lost or become unrecognizable, and as immature females may be completely demolished, this estimate of attack is the lowest possible figure.

Photomicrographs, using electronic flash illumination, have been obtained of *Onychiurus armatus* feeding on *H. cruciferae* cysts. (C. C. Doncaster.)

Nematodes Parasitic in Insects

The taxonomy, life history and development of two new species of Allantonematidae parasitic on six species of *Drosophila* have been studied. The incidence, host–parasite relationship and host specificity of two of the nematodes have been investigated in detail. The taxonomy of the Mermithidae has been reviewed. The original descriptions and diagnoses of the species and genera have been examined and a number of causes found for the well-recognized confusion in the taxonomy of this family. Suggestions have been made for the reduction of this confusion by the strict application of the International Rules of Nomenclature and the reassignment of species to genera. Both lines of work have been embodied in a thesis presented for the degree of Ph.D. in the University of London. (H. E. Welch.)

INSECTICIDES AND FUNGICIDES DEPARTMENT

C. Potter

During the current year Dr. Helen Salkeld and Miss Jill Kerridge left to go to Canada and R. van Baer left to return to Australia. F. T. Last has been seconded to the Department of Agriculture, Sudan, for two years to work on blackarm disease of cotton. The following appointments have been made: R. Sawicki to work on pyrethrum, T. Doherty to assist M. J. Way and supervise work on the rearing of the test insects, Frances Molloy to work on the histological and histochemical aspects of the mode of action of insecticides and Elaine Fairey to work on the problem of strains of insects resistant to insecticides.

K. A. Lord attended the 3rd International Congress of Biochemistry in Belgium. A grant offered by the committee of the 10th International Congress of Entomology to M. J. Way enabled him to attend this Congress in Montreal, where he read two papers. After the Congress the committee financed a five weeks' tour of Science Service and University Laboratories.

Mr. M. A. Nour from the Sudan returned to work in the department, and Mr. R. A. Harrison of the Department of Scientific and Industrial Research, Auckland, New Zealand, arrived for a stay of six months. Shorter stays for training purposes were made by P. S. Cheema of the Punjab, India, and H. Stevenson of the Kenya Pyrethrum Board.

Insecticides

Time, temperature and toxicity of insecticides

M. Das has continued his work on the effects of after-treatment temperature and time on the toxicity of contact insecticides.

The test subjects were adults of *Oryzaephilus surinamensis*, *Tribolium castaneum*, *Tenebrio molitor* and *Musca domestica*. Insects were treated by dipping them in aqueous suspensions of poison (*O. surinamensis*) or by applying measured drops of solutions of poison (all other species). In each test insects were kept after treatment at each of two temperatures, usually 28° and 10° C. In all cases except one the percentage kills increased as time passed. Counts of kill were made repeatedly on the same insects until the percentage kill from the poison stopped increasing (at the " end-point " of the test), or until the control insects themselves died.

In this way, the effect of the passage of time on the temperature coefficient of kill by each poison could be followed. Each poison gave a characteristic pattern, which was roughly the same with all the species it was tested on. Some details of the results are given in the following paragraphs. All figures are approximate.

Temperature coefficients of kill changing in size and sign. With α-chlordane on *T. castaneum* and *T. molitor*, the temperature

coefficient changed from positive to negative on the fifth day after treatment; with toxaphene on *T. molitor*, it changed from positive to negative on the fourth day; with "Valone" on *T. castaneum* it changed from positive to negative at the twentieth hour.

With rotenone on *O. surinamensis*, the temperature coefficient changed from negative to positive on the third day after treatment. Rotenone was unique in that, although there was a steady increase in kill at 28° C., there was merely a paralysis on the first day after treatment at 10° C., followed by recovery of the insects.

Temperature coefficient changing in size only. With 2-bromo-mercurithiophen on *O. surinamensis*, the temperature coefficient between 23° and 10° C. was +10 on the first day after treatment; it decreased to zero on the fifth day, but did not become negative. The results with *T. molitor* were similar, but the coefficient never became less than +2.

Nearly constant temperature coefficients. With "Dimetan" on *O. surinamensis*, the temperature coefficient was +1·5 on the first day after treatment. After this it remained unchanged, even on the sixth day.

With DDT the temperature coefficients on all four species were clearly negative (about −10), and remained almost unchanged throughout the tests. Other properties of DDT are noted below.

Special tests with DDT. Although DDT is more toxic at 10° C. than at 28° C., the toxicity does not continue to increase indefinitely as the after-treatment temperature is lowered still further. Tests on *T. molitor* showed that there was a maximum toxicity at about 6° C.; below 6° C. the temperature coefficient of kill became very strongly positive.

This positive coefficient, like the negative coefficient above 6° C., was reversible. Poisoned adult *T. molitor*, which had marked DDT symptoms after being kept at 10° C. for 2 days, showed some recovery when transferred to either −1° or 28° C. for a further 3 days; control insects were unaffected by the low temperature. Poisoned insects, kept at −1° C. for 3 days, were prostated by the low temperature, but showed no symptoms of DDT poisoning. However, they developed the usual symptoms when changed to 10° C.

Other tests have shown that the positive temperature coefficient was not due to failure of DDT to penetrate the cuticle at −1° C.; nor was it due to failure of DDT to reach its site of action at −1° C. after it had penetrated the cuticle.

It is not yet known whether the positive temperature coefficient changes in size as time passes.

Isolation and properties of insect esterases

K. A. Lord and S. R. B. Solly have continued the examination of esterases from *Blatella germanica*. Most time has been spent on fractions hydrolysing acetyl choline. The preparative methods have been improved in detail to give better yields of the acetyl choline hydrolysing preparations and to remove considerable amounts of what appears to be nucleic acid. Preparations have been examined by zone electrophoresis. It has been established that paper is not a suitable support, since the enzymes are absorbed strongly at useful pH and ionic strengths. Alternative supporting

media have been examined, and starch paste and starch gels have been utilized. It has been shown that the best cholinesterase preparations to date appear to contain other types of esterase, but the results are not inconsistent with the presence of only one enzyme hydrolysing acetyl choline. Similar results have been obtained by chromatography using ion-exchange paper (a sample of experimental material received from W. & R. Balston Ltd.) prepared from modified cellulose. The results are of sufficient promise to warrant the investigation of the method using a column, before proceeding to the examination of the properties of cholinesterase from *B. germanica.*

Preliminary investigation of the properties of the cholinesterase preparation from *B. germanica* has shown it to have a high affinity for acetyl choline. The rate of hydrolysis of acetyl choline is not reduced at concentrations of acetyl choline too low for satisfactory measurements to be made in the Warburg. A pH comparator as described by J. Burch (*Bioch. J.* **58**, 415, (1954)) has therefore been constructed and modified to improve its stability, in order to make valid enzyme estimations at lower substrate concentrations under controlled conditions and without the addition of indicators.

The pH comparator has proved of value in other experiments of this nature, and in some preliminary experiments with an esterase preparation obtained from *B. germanica* which did not hydrolyse acetyl choline; it was shown that the rate of liberation of nitrophenol from nitrophenyl acetate was increased in the presence of ethanol and butanol. At the same time the rate of liberation of acid was shown to be decreased. Glycol and glycerol decreased the rate of liberation of acid in the reaction mixture but did not appear to change the rate of liberation of nitrophenol under the experimental conditions used. It is therefore concluded that in the presence of some alcohols trans-esterification may occur.

Examination by starch block electrophoresis of preparations of *B. germanica*, largely freed from cholinesterase, indicated that there were a number of other esterases. In one experiment it seemed likely that up to six esterases were present.

Esterases in relation to the development of eggs of Pieris brassicae *and* Gryllus domesticus *and the toxicity of organophosphorus compounds*

P. brassicae *eggs.* Work on the toxicity of TEPP to *Pieris brassicae* L. has been continued by C. Potter, K. A. Lord, D. V. Holbrook and H. Salkeld. It has been shown that low doses of TEPP permit full development of the embryo to the stage where it moves, although the larvae may not emerge. Higher doses arrest development at progressively earlier stages. The dose of TEPP which permits full development of the embryo but does not allow hatching decreases only slowly as the interval between the egg being laid and treated is increased. The decrease in dosage is small compared with the expected aqueous decomposition of TEPP, even allowing for protection by solution in non-aqueous parts of the egg. It has therefore been tentatively concluded that the toxic reaction of TEPP must occur soon after its application. The overall toxicological effects, however, are not observed until the time when the

substances or their derivatives with which the TEPP has reacted are required for the metabolism of the embryo.

Preliminary experiments indicate that the enzymes hydrolysing acetyl choline and phenyl acetate in *P. brassicae* eggs are inhibited *in vitro* to about the same extent by TEPP under our experimental conditions. No definite conclusions can safely be drawn about which enzyme systems are affected in our present state of knowledge. However, since if big doses of poison are used, eggs may be killed in the earlier stages of development, before cholinesterase can be detected, there are indications that death may be produced by the TEPP by mechanisms other than the inhibition of cholinesterase.

G. domesticus *eggs.* Helen Salkeld has examined the eggs of *G. domesticus,* and S. R. B. Solly has examined the hydrolysis of three esters through the development of the eggs. The hydrolysis of acetyl choline is negligible in the early stages of development of the eggs, and only becomes apparent at the time the nervous system becomes organized, after which it continues to increase with the development of the eggs. Phenyl acetate is hydrolysed at all stages of development, but it increases as development occurs. Triacetin is hydrolysed at a fairly high and uniform rate throughout all stages of development of the egg.

A number of buffer solutions have been examined for use in connection with TEPP when poisoning *G. domesticus* eggs. These are necessary to control the pH of the aqueous solutions to which *G. domesticus* eggs must be exposed in order to ensure development under normal test conditions. Sodium succinate buffers have proved to be effective. Unfortunately aqueous solutions of 1 per cent TEPP show little toxicity to *G. domesticus* eggs when the pH of the surrounding medium is controlled.

Toxicity of organophosphorous compounds to various strains of Musca domestica

It was thought that some information on the process of poisoning by organophosphorous compounds might be gained by studying their effects on normal and resistant strains of insects.

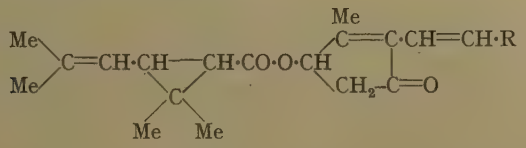
The resistance of various strains of *M. domestica* to a number of organophosphorous compounds has been compared. Four strains are under examination, a normal strain as usually reared in the laboratory and three so-called phosphorus-resistant strains. One resistant strain was kindly supplied by Dr. Busvine and the two others (strains 79 and 150) by Dr. Keiding of Denmark. Only small differences in the resistance of the strains has been detected by the techniques of bioassay that were used, although strains 79 and 150 were reported to show considerable resistance. Paraoxon, Bayer 21/199, " Diazinon ", " Chlorothion ", malathion and " Dipterex " have been selected as a range of insecticides for including in the tests. In view of the apparent lack of resistance of the insects when tested by us, an exchange of insects with Dr. Keiding has been arranged so that check assays may be made. An attempt is also being made to breed resistant strains in the laboratory.

Although the so-called phosphorus-resistant strain of houseflies supplied by Dr. Busvine was only twice as resistant to poisoning

by paraoxon, the two strains were examined for differences in the *in vitro* inhibition of enzymes which hydrolysed acetyl choline, triacetin and phenyl acetate respectively. No differences could be detected. *In vitro* tests failed to demonstrate the hydrolysis of paraoxon by extracts of housefly tissues. Tests on whole flies treated with paraoxon showed a rapid disappearance of the poison at apparently the same rate in both strains of flies. The rate of disappearance of paraoxon was followed both by the inhibition of added cholinesterase and by chromatographic methods.

The relationship between insecticidal activity and chemical structure in pyrethrin-like compounds

Although many compounds related to the pyrethrins have been synthesized and tested in recent years, so far none have contained one or more double bonds in the alcoholic side chain conjugated with the *cyclo*pentenolone ring. Work has therefore been carried out by M. Elliott to explore synthetic routes to compounds such as ((I), R = alkyl or alkenyl) below.



(I)

Apart from interest in their insecticidal potency, such compounds would contain a cross-conjugated ketonic system, which it was desired to investigate spectrophotometrically. This system was discussed by Gillam and West,* and an unsuccessful attempt to synthesize 2-but-1′-enyl-3-methyl*cyclo*pent-2-enone was made by Harper.† The following routes have been investigated in the present work :

(*a*) It is known ‡ that 2-alkyl-4-bromo-3-methyl*cyclo*pentenones can be made from the corresponding ketones by reaction with *N*-bromo-succinimide (NBS) and that 2 more bromine atoms may be introduced into the molecule by further bromination with the same reagent. Therefore, 4-acetoxy-2-butyl-3-methyl*cyclo*pent-2-enone was brominated with one mole of NBS to see whether bromine had been introduced into the α-methylene group (1′-position) in the side chain and whether it could be removed as hydrogen bromide with trimethylamine. However, all fractions so far isolated have contained up to 10 per cent of bromine, and it has not proved possible, therefore, to obtain the bromine-free keto-ester ((I), R = Et) required.

(*b*) Attempts have been made to isomerize the double bond in allethrin [(±)-2-allyl-3-methyl*cyclo*pent-2-en-4-ol-1-one (+)-*cis-trans*-chrysanthemate] into conjugation with the *cyclo*-

* Gillam, E. M. & West (1942). *J. chem. Soc.* 674.
† Harper (1946). *Ibid.* 892.
‡ Crombie, Elliott & Harper (1950). *Ibid.* 971.

pentenone ring. Both alkaline and acidic reagents tried so far have failed.

(*c*) 2-Alkyl-4-ethoxycarbonyl-3-methyl*cyclo*pent-2-enones, and thence the parent ketones, are obtained by cyclization of the products of Stobbe condensations of succinic esters with alkyl methyl ketones.* Some progress has been made towards the extension of this route to use alkenyl methyl ketones. Whereas allyl acetone condensed with diethyl succinate in the presence of sodium hydride in benzene, or with potassium *t*-butoxide in *t*-butanol without double-bond migration (half-ester, $\lambda_{max.}$ 2200 Å., ϵ, 4260), the product from reaction with potassium *t*-butoxide suspended in ether appeared to have undergone a double-bond shift ($\lambda_{max.}$ 2400 Å., ϵ, 13,600), producing what may be 3-ethoxycarbonyl-4-methylocta-4 : 6-dienoic acid. Cyclization of this compound should produce a *cyclo*pentenone with a double bond in the 1′-position of the side chain, but experiments have not yet proceeded far enough to confirm whether this can be carried out.

Toxicity and persistence of insecticidal deposits

Effect of additives on DDT emulsions. J. Ward and E. M. Gillham have studied the toxicity of deposits of DDT made by spraying emulsions containing small amounts of additives which modify the crystal form. The toxicity of films of these materials produced by spraying them on to wax-coated glass plates has been measured, using the technique of 6-day exposure periods with *Tribolium castaneum* Hbst., described below in the bioassay section. Deposits from standard emulsions on wax-coated and on plain glass plates have been used for comparison. So far, despite the considerable effect of the additives on crystal form, no great differences in toxicity between the standard and the modified emulsions have been found. This may be because of the inadequacy of the biological assessment technique. Although the technique of long exposure periods gives satisfactorily precise results, it is not an adequate substitute for a test using a shorter period, as previous work has shown that differences in toxicity of different types of deposit tend to become less as the exposure period is increased. For this reason an attempt has been made to discover the causes of the irregular results obtained with the same test method when shorter exposure periods are used. This work is described in the section on bioassay. Work has also been started on an alternative method using *Musca domestica*, which is also described in the section on bioassay.

Rate of evaporation of insecticide films. Previous attempts to measure the rates of evaporation of DDT films under standard conditions have shown that reliable results can only be obtained if the rate of ventilation is controlled. This has been achieved by constructing a ventilated cabinet in which the air-flow is made laminar by a number of " honeycomb " screens. The plates are carried in slots in a metal rack which has been carefully made so that the plates are parallel with one another and at right-angles to the air-stream. The apparatus is kept in a well-ventilated constant-temperature

* Elliott (1956). *J. chem. Soc.* 2231.

room at 24–25° C. With a wind speed of 8 m.p.h. (which at present cannot be varied) the variation in rates of evaporation between plates in different positions in the rack has been found to be satisfactorily small.

Using the wind tunnel, it has been shown that evaporation from the emulsion-sprayed plates used is linear with time until about two-thirds of the deposit has evaporated. At this stage most of the long outgrowths from the centres of crystallization have been lost, and only compact clumps at the centres remain. Thereafter, evaporation continues at a lower rate. Previous work had suggested that the rate of evaporation was independent of the initial density of the deposit. Recent results have confirmed that this is so during the initial linear period of evaporation for the deposits of emulsions of DDT on glass so far examined. For the conditions in the ventilated cabinet, i.e., 24–25° C. and 8 m.p.h. windspeed, the rate of loss is about 0·4 μg./sq. cm. per day.

Persistence of benzene hexachloride in soil

It was mentioned in last year's report that an experiment on the tainting of crops by applications of insecticide to soil was being conducted by the National Vegetable Research Station, that Rothamsted had agreed to analyse soil samples for benzene hexachloride and that a suitably sensitive method of analysis was being sought. J. Ward and J. Samuel have continued this work, and have devised an analytical method. The method devised is capable of estimating down to 2 parts of BHC in 10^8 parts of soil, but the precision of the results still leaves something to be desired, and it is hoped to improve the method in this respect. An outline of the method is given in the section on analytical techniques.

Sixty-six soil samples have been analysed using this method. The results show that BHC applied in March and worked into the top 4 inches of soil does not penetrate farther into the ground, though during the hot summer of 1955 about 70 per cent of the BHC was lost. After the vegetables had been harvested, the land was ploughed to a depth of 8 inches. As might be expected, this operation redistributed the insecticide to the ploughing depth. The soil was again sampled in April 1956, when it was found that there had been no significant change in the total BHC content of the soil during the winter.

Analytical and bioassay techniques

Estimation of BHC in soil. Steam is passed through a sample of the soil and carries with it the BHC, which is appreciably volatile. The BHC is extracted from the condensate with carbon tetrachloride which has been specially treated to remove all traces of aromatic substances. Impurities from the soil are removed by passing the carbon tetrachloride solution through a column, the top part of which is packed with nitrating mixture supported on kieselguhr, the lower with activated alumina. Impurities are nitrated in the upper part of the column, and the nitro-compounds formed are adsorbed on the alumina. BHC passes through without loss.

The carbon tetrachloride solution is concentrated under reduced pressure in a flask immersed in a bath at 10° C. When the volume

has been reduced to 1 ml., a small quantity of piperidine is added and the solution is heated under reflux in semi-micro equipment with standard ground-glass joints. The piperidine dehydrochlorinates BHC to 1 : 2 : 4-trichlorobenzene. Nitrating acid is added, which destroys the excess piperidine and nitrates the trichlorobenzene. After boiling off the carbon tetrachloride and diluting the acid mixture, the dinitrotrichlorobenzene is extracted with benzene. An aliquot portion of the benzene is evaporated down to 0·2 ml., and a colour is formed by adding benzyl cyanide and acetone and shaking with concentrated aqueous potassium hydroxide. The depth of colour is measured using micro-cells which give a 1-cm. light-path with 0·3 ml. liquid.

The method of recovering BHC from soil by steaming gives quantitative results with some types of soil, but with soil from the Fens it was found to give a low recovery. An alternative method of extraction is being developed. The method of analysis may also prove useful for potatoes and other vegetables; using the steam extraction process, we have found that 0·06 p.p.m. of BHC can be recovered from potatoes grown in soil treated with 1½ lb./acre of gamma BHC, but this must be regarded as a minimum figure, as we have, has yet, no information on the efficiency of recovery of BHC from potatoes.

Bioassay of contact toxicity of insecticide deposits

Assessment using adult Tribolium castaneum. A deposit is produced by spraying the surface with the insecticide in aqueous medium using a Potter Tower. The method used up to the present to assay the toxicity of deposits has been as follows: groups of 10 *Tribolium castaneum* (Hbst.) are confined on the surface to be tested in glass rings, for a period of either 4 or 24 hours, at a temperature of 20° C., R.H. 60 per cent. During exposure to the deposits the insects are kept in the dark. They are then removed from the deposits by means of a drawn-out glass tube attached to the vacuum-line, with which they can be picked up individually and transferred to specimen tubes. After a further period of 5 days at the same temperature and humidity, the dead are counted. Four groups, each of 10 insects, are used as replicates for each level of deposit density. As was mentioned in the last report, this method of assessment suffers from the disadvantage that the kills in the replicate groups of 10 are more variable than can be accounted for by random sampling-error, and consequently the confidence limits of the LD50s obtained in this way are wide, unless the number of replicates is greatly increased.

An attempt was made to list all the likely causes of variation and examine them. The following were considered:

1. The insects are not selected in a random manner when the groups of ten are counted out from the culture.
2. The deposits are unpredictably variable in character, so that the replicate groups of ten insects do not receive identical treatments.
3. The environments of the groups during exposure are not identical.

4. It has been found that if insects are active the mean amount of insecticide picked up is greater than if they were inactive. If different groups differ in the presence or absence of active individuals and active individuals stimulate the group, this may prove a source of variation.

5. An occasional exceptional insect might pick up a dose very much greater than the average, then transfer it to the other members of its group during the waiting period before mortality assessment.

Experiments in which groups of insects were washed with acetone after removal from the deposit, and then the acetone analysed for DDT, showed that the variations in mortality are accompanied by variations in the amount picked up by the insects. Further evidence of the relevance of the amount picked up was obtained by exposing the insects to the deposits for 6 days instead of 24 hours and counting the dead at once. The longer exposure period resulted in the variations in mortality between groups being much reduced.

Non-random selection of insects from the culture is avoided by putting the insects into the glass circles one at a time, putting one into each ring before putting the second into the first ring and so on, so this source of variation can be ruled out.

Variability of the deposits has been investigated by using two successive batches of insects on the same deposits. If the deposits were irregular, it would be expected that an area of deposit which caused a low kill in the first batch of 10 insects would also cause a low kill in the second. The experiment showed that in many instances an area of film that gave a low kill with the first batch of insects gave a high kill with the second. This showed either that the toxicity of the deposit was altering between exposures or it was not the main cause of the variability in kill between replicates. There is some evidence that the physical state of the deposit could have altered considerably between exposures, and this still remains as a possible source of variation.

Variations in environment during exposure were as far as possible avoided by covering the trays of plates with opaque paper to exclude light, and storing at constant temperature and humidity.

The explanation that the insects of a group have some influence on one another during the period of exposure is being studied by exposing insects singly, instead of in groups, and comparing both the mean kill and the variability with those obtained by the standard method.

The possibility of transfer of insecticide from one insect to another during the storage-period before counting the kill was also eliminated as an explanation of the variation by the following experiment : Two sets, each of 10 groups of 10 insects, were exposed to a DDT deposit which would give about 50 per cent kill. One set was removed and kept in the usual manner, the other was randomized at the time of removal from the deposit, so that the insects which were exposed to the deposit as a group were distributed among the 10 groups during storage. The variability of kill was much greater for the groups of insects which had not been randomized than for those

which had, and among the latter it was no greater than was to be expected on statistical grounds.

Assessment using adult Musca domestica. Insects may be killed by the penetration into them of insecticide, the particles of which continue to adhere to the substrate; or they may be killed by particles, originally adhering loosely to the substrate, which they pick up and carry away when they are removed from the deposit. The two methods may be distinguished as killing by direct action and by pick-up. Differences in ease of pick-up between different deposits may be expected to show up more clearly if the test-method uses a short exposure period rather than a relatively long one, as required by *T. castaneum*. A technique is therefore being developed by R. A. Harrison for comparing the biological activity of deposits prepared from different formulations and on different substrates, using *Musca domestica* as the test insect. Tests are being carried out to determine the performance of an apparatus which gives flies no choice but to walk on the insecticidal deposit and to determine the factors influencing the results. The apparatus confines flies between two surfaces, the lower surface being interchangeable with a test surface at will. The distance between the surfaces has a considerable effect on fly mortality. When the apparatus is inverted and flies are forced to walk upside down on the deposit the mortality is lower than when the apparatus is normally orientated and the flies are in a normal upright position.

Deposits of DDT (approx. 5·0 μg./sq. cm.) prepared on glass plates from a DDT emulsion show an initial rapid decline in toxicity when successive test samples of flies are exposed to them.

Bioassay using a measured-drop technique and Musca domestica *adults*

A convenient procedure for handling *M. domestica* for bioassay purposes, particularly where a measured-drop technique is used, has been elaborated during the course of work on the action of synergists of pyrethrins. It has already been applied to other insecticides. The adult flies are normally sexed the day before a test is made. The adult flies are reared in 9-inch-cube cages which are placed on trays of ice in a cold cabinet at 5° C. (approx.). The live flies migrate to the top of the cage in a torpid condition. The cage is then lifted from the tray which forms the base of the cage and quickly placed on a clean tray. In this way the live flies are separated from the dead and the normal debris of a rearing cage. The cage is then thoroughly cooled in a deep freeze to completely immobilize the flies, which are then shaken down into a clean tray. The top of the cage is removed and the tray placed in a cold cabinet fitted with a window and hand hole. The flies are then sexed and placed in petri-dishes whilst immobilized. The insects are then allowed to recover and are kept 24 hours at the temperature of treatment, usually 25° C. The following day, immediately prior to treatment, the petri-dishes containing the flies are cooled in the ice-box of a refrigerator at −8° C. for 5 minutes before applying the insecticide as a measured drop to the ventral surface of the thorax. When the solvent is volatile, e.g., acetone, it evaporates whilst the flies lie on their backs before they recover sufficiently to turn over and walk.

Using this technique, a series of very satisfactory probit lines were obtained.

Detection and identification of toxic substances in poisoned bees

From time to time during the summer months, samples of dead bees are received by the Bee Advisory Service of the National Agricultural Advisory Service for determination of the cause of death. The beekeeper generally wants to know whether his bees have been poisoned, and if so, the identity of the poison. This year, samples of bees which did not show signs of disease have been passed to this department by the National Agricultural Advisory Service, and an attempt has been made by J. Ward and P. H. Needham to develop methods for identifying the toxic agent, using a combination of chemical and biological methods. A method capable of doing this should be quite generally useful for identifying traces of insecticides in other materials.

Published work on this subject originates mainly in Germany and Switzerland, and the methods described are all tentative. Several of these depend on bioassay with larvae of *Aëdes aegypti* as test species, and these methods were taken as a starting point. None of them is capable of separating the insecticide from all traces of the waxy material which is obtained when bees are extracted with fat-solvents, and it was found that the wax interfered with the bioassay, either by causing mortality among larvae treated with extracts from control (unpoisoned) bees or by suppressing the toxicity of added insecticide, presumably by preventing it from dissolving in the water in which the larvae were swimming. Attempts were made to remove the wax by partitioning the extracts between petroleum ether and wet alcohol, but this procedure was only partially successful. Two methods of separation employing chromatographic columns were tried; that described by Erwin *et al.* (*J. Agric. Fd Chem.* **3** (1955), 676) as a means of separating insecticides from other matter in vegetable extracts appeared to be promising.

When a chromatographic column is used to dewax the bee extract, some indication of the nature of the insecticide present is obtained by observing its rate of progress through the column. A further indication can be obtained by treating the dewaxed extract with reagents which destroy some insecticides but not others. Treatment with oleum, for instance, will destroy all commonly used insecticides except lindane, DDT and chlordane. If an extract remains toxic to mosquito larvae after treatment with oleum one of these three insecticides is present. The method of separation and identification is being further developed.

The biological material used for indicating the presence of poison in the extracts of the bees was kindly supplied by the Cooper Technical Bureau, Berkhamsted, Herts. Eggs of *Aëdes aegypti* were obtained as required.

Larvae were obtained from the eggs and cultured in distilled water on " rat cube " (M.R.C. diet 41) at a temperature of 27·5° C. Three-day-old larvae were used for detecting the poisons.

The method of conducting the tests on the extract was rather rough, as it was devised at very short notice. A more elaborate and precise method has been developed for next season.

Of the 10 samples received from the Bee Advisory Service 8 were found to contain insecticidal material. The insecticide was tentatively identified in 5 samples, 3 as lindane, 1 as dieldrin or endrin and 1 as a nitrophenol.

Factors influencing the resistance of Drosophila melanogaster *to insecticides*

This work has been continued by F. Tattersfield, J. Kerridge and E. Fairey. It has previously been noted that the addition of certain protein-containing materials, such as yeast and casein, to a sugar- or honey-containing medium increased significantly the resistance to DDT of adult *D. melanogaster*. During this year's work the result was confirmed that the addition to a glucose–agar–nipagin medium of live yeast or casein (vitamin-free) or casein (soluble) increased the resistance to DDT of the *D. melanogaster* adults which were fed on it to about the same degree; dead yeast was not so effective. It was also confirmed that, whereas the adults fed on this medium plus yeast, dead or alive, produced eggs and larvae which passed through the whole life cycle, those fed on it plus casein did not.

Preliminary work was also started on the effect of population density of larvae upon the resistance of the resulting adults. It has been shown in the previous years' work that very high densities of adult *D. melanogaster* either males or females (separately or mixed) reduced their resistance, but that the pattern depended on the sex. The problem of the effect of the population of the larvae proved more complicated. The size of the resulting adults in general declined with the population density, but this was not correlated in any simple way with the resistance to DDT. The work is to be repeated and an attempt made to ascertain whether a selection for higher resistance is possible by increasing the population per unit of food available. The slopes of the respective log concentration–probit lines, in addition to their relative positions with respect to each other, emerged as a matter of importance in these investigations, as they indicate the relative degree of variation in resistance within the respective populations, and the extent to which the slopes may have been affected by the death-rate caused by the relation between population densities and available food.

During the year Miss Jill Kerridge left the department to go to Canada. This caused some delay in pursuing the work. It has been possible, however, with the help of other assistants in the department, to carry out a survey in some detail of the effects of the B-vitamins upon resistance. It was found in preliminary tests that neutralized nucleic acid and sodium nucleate derived from yeast gave a definite increase in the resistance to DDT of adult *D. melanogaster* fed upon a glucose–agar medium containing it. The sulphates of iron, manganese and magnesium and the potassium phosphates K_2HPO_4 and KH_2PO_4, important constituents of Tatum's salt mixture, have either little or no effect that could be regarded as significant. If anything, particularly in the case of the males, the phosphates at the concentrations tested slightly reduced resistance. A few amino acids tested gave uncertain results.

With *D. melanogaster* the B-vitamins are much more important

than any others, as they determine whether the life cycle—larvae, pupae and adults—will be carried through successfully. Many of these vitamins act as co-enzymes. Tests were made with vitamin B_1 (aneurin, thiamine), B_2 riboflavin, B_6 pyridoxin, nicotinamide, folic acid, calcium D-pantothenate and choline chloride. None of them when used in a glucose–agar medium at relatively high concentrations gave significant increases in the resistance to DDT of adults fed for a week upon them. The problem arose, however, whether the effect produced might not depend upon the concentration of DDT used in the spray tests.

The work is being continued using media containing nucleic acid, with both a number of salts and certain vitamin-B mixtures.

It is proposed that Miss Elaine Fairey undertakes the selection of DDT-resistant strains by feeding the larvae of *D. melanogaster* upon DDT-containing media.

Pyrethrum and other plant products

Pyrethrum synergists. Experimental work by C. Potter, K. A. Lord and D. V. Holbrook to compare the effects of piperonyl butoxide and sulfoxide on the toxicity of pyrethrins to *Musca domestica* has now been completed. The results are being examined in conjunction with those obtained using *Tenebrio molitor* to determine if specificity occurs and, if so, the nature of it.

A major difficulty in comparing the action of either a number of synergists on one species or a single synergist on a number of species arises from the difficulty of summarizing the experimental data. We believe that we have elaborated a convenient method of obtaining and expressing data for the comparison of the effects of different synergists.

For each synergist a number of probit lines covering a wide range of pyrethrins–synergist ratios are constructed, either by varying the amount of pyrethrins and keeping a constant ratio of synergist to pyrethrins, or by keeping the concentration of synergist constant and varying the amount of pyrethrins, or by keeping the pyrethrins constant and varying the amount of synergist.

Any desired mortality level may then be selected, and for each of the probit lines the amount of synergist and pyrethrins giving this kill is obtained. From these data a curve is constructed which shows the amounts of pyrethrins and synergists, covering all possible ratios, which will produce the specified kill. When these curves have been constructed for each of the synergists to be compared the comparison of their effects over a whole range of pyrethrins–synergist mixtures may be made at a glance.

These curves may conveniently be used when comparison at fixed ratios of pyrethrins to synergist are required, since straight lines drawn through the origin of the graph give fixed ratios. These data are of practical importance, since, in the field, only one ratio is used and the amount of poisons received by individual insects is variable.

Further examination of the results has shown that in our experiments the results may be expressed by the equation

$$Y = Px + Sz + C$$

where Y = probit mortality; x = log pyrethrins concentration; z = log synergist concentration; P, S and C are constants. In addition to the information obtained on the relative performance of piperonyl butoxide and sulfoxide on the two species of insects, the results show that there is a specificity of effect with both synergists, since it was possible to increase the toxicity of pyrethrins to a much greater extent with one of the species tested than with the other.

Toxicity of Millettia dura *extracts.* At the request of the Colonial Products Laboratory a preliminary assessment of the toxicity of various extracts of *Millettia dura* was made by P. H. Needham. The plant material was obtained from Kenya.

The extracts tested were: (*a*) chloroform extract of the seeds; (*b*) chloroform extract of the roots; (*c*) petroleum ether extract of the seeds.

The chloroform extract, which was the most toxic one, was found to be one-quarter to one-fifth as toxic as rotenone when applied by a measured-drop technique to adult *Phaedon cochleariae* (see Table 1). This extract was then separated into the alkali-soluble fraction and the neutral fraction. These two were tested against adult *P. cochleariae*, with the result that the neutral fraction showed the same toxicity as the original chloroform extract, and the alkali-soluble fraction was non-toxic at 0·5 per cent w/v.

TABLE 1

Toxicity of extracts of Millettia dura *to adult* Phaedon cochleariae *in comparison with rotenone*

	Relative toxicity
Rotenone	100
Chloroform extract of the seeds	23
Chloroform extract of the roots	4
Petroleum ether extract of the seeds	1
Neutral fraction of chloroform extract of seeds ...	24

Insect rearing

Species reared. The following insect species were reared in the department during the year. They include 10 plant-feeding species and 17 feeding on stored products.

Plant feeding

HEMIPTERA	*Megoura viciae* Buck.
	Aphis fabae Scop.
	Myzus persicae Sulz.
	Acyrthosiphon pisum Harris
LEPIDOPTERA	*Pieris brassicae* L.
	Diataraxia oleracea L.
	Actias selene Hubner.
COLEOPTERA	*Phaedon cochleariae* F.
DIPTERA	*Leptohylemyia coarctata* Fall.
	Hylemyia antiqua Meig.

Stored product, domestic and medical

HEMIPTERA	*Dysdercus fasciatus* Sign.
ORTHOPTERA	*Blatella germanica* L.
	Blatta orientalis L.
	Periplaneta americana L.
	Gryllus domesticus L.
LEPIDOPTERA	*Achroia grisella* Fabr.
	Ephestia kühniella Zell.
COLEOPTERA	*Oryzaephilus surinamensis* L.
	Oryzaephilus mercator Fouv.
	Tribolium castaneum Hbst.
	Tribolium confusum Duval.
	Tenebrio molitor L.
	Calandra granaria L.
	Trogoderma granarium Everts.
DIPTERA	*Aëdes aegypti* L.
	Drosophila melanogaster Meig.
	Musca domestica L.

Four constant-temperature rooms are now working in the West Building, one with controlled lighting for the rearing of plant-feeding species. A number of different strains of *M. domestica* are being reared for work on organophosphorous resistance.

Diapause in Leptohylemyia coarctata *Fall.* This work, by M. J. Way, is nearing completion. Temperature requirements for termination of diapause in the egg have been determined, the range being from about +12° to about −24° C. Diapause is terminated slowly at +12° C., and there is also a high mortality. Within the range +12° to −6° C. it is terminated most rapidly and efficiently at +1° to +3° C. It is terminated slowly at −6° C., but at temperatures below this the rate increases rapidly, at any rate for the later stages of diapause. The eggs freeze at −26° to −28° C.; this kills them.

The treatment of *L. coarctata* eggs at temperatures around −20° C. makes it possible to shorten the length of this stage from about six to three months. This is useful for laboratory rearing, and it also greatly extends the period during which newly-hatched larvae can be made available for experimental work.

Wheat bulb fly Leptohylemyia coarctata *Fall.*

Laboratory rearing. A paper on this subject by R. Bardner and J. Kenten is now in the press. Bad weather consistently hindered the routine collection of adult females for breeding purposes, but finally about 16,000 eggs were obtained for experimental purposes. Research into a suitable method of rearing larvae on an artificial diet is continuing.

Insecticidal control (R. Bardner)

Box experiments. Thirteen different insecticides were formulated as seed dressings (γ-BHC, heptachlor, parathion, dieldrin, endrin, isodrin, aldrin, DDT, " Chlorothion ", " Metasystox ", " Systox ",

" Dipterex ", " Diazinon ") and a comparison made of the protection they gave against wheat bulb fly attack. The technique used was similar to that described in previous annual reports. None was outstandingly better than γ-BHC, dieldrin or aldrin, though heptachlor and parathion were comparable, and our formulations of these and other materials are being compared in small field-plot trials by the National Agricultural Advisory Service. This work is being continued.

A comparison of different methods of applying dieldrin seed-dressing to wheat showed that the phytotoxicity experienced in last year's field experiment was largely due to treating the wheat with acetone, which was used as a solvent for the dieldrin.

Field experiment. In 1955–56 the experiment in Pennels Piece was in its second season. The general design was described in *Rep. Rothamst. exp. Sta. for* **1955**. There were 5 different treatments in 5 randomized blocks of 6 plots each, but it was observed that a drought in April was associated with a decline in larval numbers in all blocks except one, situated on very wet soil. This is the second year in succession that a drought in late spring appeared to kill larvae, and this may be an important factor in controlling the wheat bulb fly population on heavy clay soils.

The treatments were as follows: (1) untreated (2 plots per block); (2) 4 per cent dieldrin dust at 1 cwt./acre combine-drilled with seed on 1 November 1955; (3) 4 per cent dieldrin dust at 1 cwt./acre broadcast on surface on 16 February 1956; (4) sprayed with parathion on 8 March 1956 at 0·1 per cent v/v., 100 gal./acre; (5) sprayed with parathion on 12 April 1956 at 0·1 per cent v/v. at 100 gal./acre.

Though larval numbers were comparable with those recorded for 1955, the plants had tillered well by the time attack occurred and, as a consequence, the proportion of attacked tillers was lower. Table 2 gives the results of sampling on 27 April 1956.

TABLE 2

Effect of insecticides in reducing plant damage by wheat bulb fly *

	Untreated	Dieldrin, combine-drilled	Dieldrin, broadcast	Parathion, early spray	Parathion, late spray
Damaged tillers	341	40	61	199	131
Decrease ...	—	301	280	142	210

Least significant difference at 5 per cent level between treatments, 88.
Least significant difference at 5 per cent level between untreated and treated, 76.

* All numbers in thousands per acre.

At the 5 per cent level all treatments showed a reduction of damaged tillers compared with the controls. There was no significant difference between the dieldrin treatments or between the parathion treatments. The broadcast treatment was significantly better than the early parathion spraying, but not the late spraying treatment and appeared to be rather slow in killing larvae compared with the combine-drill treatment. At harvest, however, the broadcast treatment was the only one to give a significant increase in yield, as shown in Table 3.

TABLE 3

Effect of insecticides for wheat bulb fly control on grain yields

Grain yield, cwt./acre (85 per cent dry matter)	Untreated	Dieldrin, combine-drilled	Dieldrin, broadcast	Parathion, early spray	Parathion, late spray
Mean	46·2	45·9	52·3	45·7	48·5
Increase ...	—	−0·3	+6·1	−0·5	+2·4

Least significant difference at 5 per cent level between treatments, 4·5.
Least significant difference at 5 per cent level between untreated and treated, 3·9.

The possibility that the broadcast treatment was controlling a pest attacking the crop after the conclusion of the bulb-fly attack is being investigated. Further work on the optimum dosage rates and time of application of these treatments is in progress. The results of the first three seasons' work on insecticidal control are now being prepared for publication.

Mode of action of the insecticides. Further laboratory and pot experiments by M. J. Way and R. Bardner confirmed that γ-BHC-treated plants are distasteful to newly hatched larvae of *L. coarctata*. Aldrin-treated plants were attacked, but the larvae died after feeding for varying periods of time within the stems. Experiments to determine whether the γ-BHC-treated plant was toxic as well as repellent and whether the action of aldrin and dieldrin was due to their systemic properties gave inconclusive results. The work is being continued.

Bean aphid Aphis fabae *Scop.*

Effect of planting date on infestation and control. This experiment by M. J. Way and T. Doherty was essentially similar to one done in 1955. Field beans were planted at four different dates and, for each planting date, yields of unsprayed plots were compared with those of plots sprayed once and twice with "Metasystox" (0·05 per cent active ingredient and 100 gal./acre). Aphid counts were made at weekly intervals from the beginning of June to the end of September.

As in 1955, few aphids migrated to the bean crop in June, but the populations never built up even on the late-sown crops. The aphid numbers on unsprayed plots never rose above an average of 1·4 per plant, compared with a peak of 4,170 per plant in the 1955 experiment. The weather (hot and dry in 1955 and cold and wet in 1956) is considered to be the main cause of the different types of population which developed.

Table 4 shows that the insecticidal treatments gave some significant increases in yields of grain. It seems unlikely, however, that these result from control of the very few aphids present.

This series of experiments, which will probably be completed in 1957, shows that insecticidal control is always justified when there is a big migration of bean aphids from the winter host to beans in June. When there is a small migration, an insecticide should be applied if the crop is sown late. This ensures control of damaging

aphid populations which might otherwise develop if the weather is favourable.

TABLE 4

Effect of insecticides to control Aphis fabae *on grain yield of field beans*

Time of spraying	Grain yield, cwt./acre, few different sowing dates			
	10 March	3 April	24 April	15 May
Untreated	26·7	26·9	20·9	13·7
22 June	28·5 *	29·5 *	21·6	13·9
11 July	27·6	28·9 *	22·1	12·9
22 June and 11 July ...	26·1	28·3 *	20·7	14·7

* Significantly different from untreated at 5 per cent level.

Relative importance of biological and chemical control. This work is being continued by M. J. Way and T. Doherty in collaboration with C. J. Banks of the Entomology Department.

Naturally occurring populations of *A. fabae* and its parasites and predators were estimated on various host plants, including *Euonymus europaeus*, field beans and *Chenopodium* sp. In addition, caged plots of these plants were artificially infested with aphids. One type of cage covered with dieldrin-treated terylene netting was used to exclude predators and parasites, while another type which gave comparable climatic conditions allowed free access to the natural enemies. The aphid populations developing in predator-free and predator-exposed plots were determined. With field beans the crop yields were compared with those of plots treated with an aphicide spray. These gave some measure of the relative efficiency of biological and chemical control.

Natural populations of *A. fabae* on *Euonymus* in spring were very small, and few alatae migrated to field beans in midsummer. Overwintering predators and their progeny which stopped build-up of aphids on *Euonymus* were unable to multiply on the few aphids which developed on beans and later on *Chenopodium*. However, between October and December, when most predators had begun hibernating, populations of the aphid developed on *Euonymus* and laid eggs.

The combination of fairly big overwintering aphid populations and small predator populations should lead to populations of aphids on beans during 1957 (at any rate in the Harpenden area), which should justify insecticidal control.

The control of the vectors of potato virus diseases

The experiments on the control of the spread of aphid-borne potato viruses carried out by P. Burt in collaboration with L. Broadbent of the Plant Pathology Department were continued this year.

Previous work (see *Rep. Rothamst. exp. Sta. for* **1955**, 129) had suggested that applying DDT emulsion at low volume might be as effective as application at high volume in controlling potato aphid populations. In the main experiment the ability of DDT emulsion applied at high or low volume 4 or 6 times during the season to prevent the spread of leaf-roll virus and virus Y was tested. A spraying machine with some unusual features, including an unorthodox arrangement of spray-jets, was lent us by courtesy of the Colorado

Beetle Machinery Depot of the Ministry of Agriculture and used throughout the experiment; it performed very well. Aphid control was good, although the weather seriously interfered with the spraying programme (see report of the Plant Pathology Department).

Farmers carrying out commercial seed-retention trials have questioned the necessity of using underleaf as well as overhead jets when spraying potato crops to control aphids. A small, preliminary, non-replicated experiment was done to see what would be the effect on an aphid population of: (1) applying DDT emulsion to a potato crop from overhead jets only (plot A), and (2) from overhead and underleaf jets (plot B); in both treatments 2 lb. DDT was applied per acre. The sprayed plots were 8 rows wide and about 30 yards long, and were separated by 18 unsprayed rows which served as a control (plot C). The crop had not been sprayed previously and was only sprayed once during the experiment (23 July). Aphid counts on upper, middle and lower leaves were done immediately before spraying and at intervals afterwards until 25 days after the crop was sprayed, 5 counts being carried out in all.

After spraying, on plot B the number of aphids fell rapidly to a fairly low level, thereafter remaining nearly constant until the end of the experiment. The number on plot A fell much more slowly, so that even after a week the populations on plots B, A and C were 265, 696 and 1,290 per 100 leaves. The population on plot A continued to fall steadily and finally coincided with that on plot B on the seventeenth day after spraying (9 August); numbers on B, A and C were then 158, 158 and 1,162. The populations on all plots then declined rapidly from natural causes.

From the third day after spraying onwards, the difference in numbers of aphids found in the two sprayed plots was confined almost entirely to those on the lower leaves; as the lower leaves carried most of the aphids in the crop (during the 25 days the experiment lasted, aphids were between 1·1 and 1·9 times as numerous on the lower leaves as they were on the upper and middle leaves taken together) the difference was important.

The results suggest that to reduce aphid numbers in a potato crop quickly with contact insecticides, the plants must be thoroughly covered with insecticide, and that results obtained with underleaf spray jets as well as overhead jets are superior to those obtained with overhead jets only. Further information is needed about the distribution of aphids on the plants throughout the season and on the effect of repeated overhead sprays.

The percentages of virus spread which occurred in the 1955 experiment are given in the report of the Plant Pathology Department, together with information on other potato virus experiments.

Fungicides

Time, temperature and toxicity of fungicides (A. H. McIntosh)

The slide-germination method for testing fungicides *in vitro* has been adapted for use with Böttcher's slides. The cells are filled to the top and then closed with cover glasses. In this way, drops of spore suspensions can be kept for up to 3 days without any evaporation; if there is no cover glass, evaporation from a 0·2-ml. drop may

be as much as 47 per cent in 2 days at 10° C., even in an atmosphere "saturated" with water vapour.

This slide method was used with spores of *Botrytis fabae*, which were exposed continuously to solutions of water-soluble fungicides for up to 3 days at each of three temperatures (10°, 20° and 25° C.). Counts of the numbers of spores germinating were made each day. The "optimum" temperature for germination of this species is about 25° C. Germination occurred more quickly at 25° C. than at any lower temperature; but the percentage of spores which finally germinated was hardly affected by temperature in the range 10–25° C. It was common to find that at least 90 per cent of the spores had germinated within 24 hours at 10° C. The upper lethal temperature is about 28° C.

The effects of temperature on toxicity seem to be much more important than those of time. The following compounds had positive coefficients of toxicity between 25° and 10° C.: *n*-butyl alcohol (3·1 in 24 hours), *tert*-butyl alcohol (3·0 in 24 hours), mercuric chloride (6·0 in 24 hours) and mercuric bromide (3·4 in 24 hours). These poisons were all at their most toxic at the "optimum" temperature for germination and not, as might have been expected, at 10° C. In contrast, the toxicities of the following compounds were almost independent of temperature in the same range: 8-hydroxyquinoline sulphate, sodium pentachlorophenate, phenyl mercuric acetate, acetic acid, copper sulphate, silver nitrate and mercuric acetate.

The difference between the temperature coefficients of the mercuric halides and that of mercuric acetate may be associated with the fact that the halides are unionized in solution, whereas mercuric acetate is partly ionized.

The alcohols are "physical" poisons. *n*-Butyl alcohol is only partly soluble in water, and is less soluble at 25° C. than at 10° C. The increased toxicity of *n*-butyl alcohol at 25° C. was not a "Ferguson" effect, because *tert*-butyl alcohol, which is soluble in water in all proportions, gave a temperature coefficient of the same size.

The effects of time on toxicity were very small. There was often a slight increase in median lethal concentration between the first and third days. This increase, if it occurred at all, was always greater at 10° C. than at the other temperatures. Mercuric bromide showed the greatest increase of this type (1·7 times); there was a corresponding increase in the size of the temperature coefficient of toxicity.

Fungal physiology in relation to bioassay of fungicides

The relation between spore germination and infectivity has been studied by F. T. Last. With increasing age of culture, the ability of *Botrytis fabae* conidia to infect broad bean leaves, *Vicia faba*, is lost more rapidly than their ability to germinate on glass slides. Although 80 per cent of conidia from 40 day-old cultures germinated, only 10 per cent from 20 day-old cultures could infect.

Similarly, a shorter exposure to ultra-violet is necessary to reduce the infectivity of *B. fabae* conidia than to reduce the ability to form colonies on agar. When the logarithm of the percentage survival is plotted on the ordinate against the duration of exposure

to ultra-violet, and when the straight part of the curve is extrapolated to the ordinate, the point of intersection gives a measure of the number of viable centres which have to be inactivated. Four and 8 centres were inactivated to prevent infection and germination respectively.

As with *B. fabae,* ultra-violet reduces the ability of *Erysiphe graminis* conidia to infect barley more readily than the ability to germinate on glass slides.

Griseofulvin and club-root of cabbages caused by Plasmodiophora brassicae

In more precise experiments by F. T. Last in collaboration with I. Macfarlane of the Plant Pathology Department, the retardation of club development when griseofulvin was sprayed on to the foliage was not found to be caused by griseofulvin translocated after absorption through the leaves. It was, however, caused by the absorption through the roots of griseofulvin which had reached the soil.

In addition to retarding club development, soil applications reduced the number of plants clubbed. As before, there was a strong interaction between inoculum concentration and the percentage of plants clubbed—the lower the inoculum concentration, the fewer the plants clubbed.

ENTOMOLOGY DEPARTMENT

K. Mellanby

General

H. F. Barnes spent two and a half months in Canada and the U.S.A., attending the Tenth International Congress of Entomology at Montreal and afterwards visiting research stations, agricultural colleges and universities in Ontario, Washington, D.C., Missouri, Kansas, Nebraska, Iowa, Minnesota and New York State.

F. Raw returned from secondment to the West African Cocoa Research Institute in Ghana. C. G. Johnson departed on secondment to the same institution in December; he will take up duties as Acting Director for three months, and then remain for a further year as Chief Entomologist.

P. W. Murphy and R. M. Dobson attended the 6th Congrès International de la Science du Sol in Paris and read papers. P. W. Murphy read a paper on the rôle of soil acarina in the decomposition of leaf litter at the British Association meeting at Sheffield.

J. C. da Silva Dias of the Portuguese Agricultural Service (British Council Scholar) joined the department.

G. W. Heath was awarded the Ph.D. of London University, having submitted a thesis entitled *Biological Studies in Gall Midges* (*Cecidomyidae*).

The work of the department has been seriously inconvenienced by the delay in erecting insectaries and glass-houses adjacent to the West Building. Makeshift accommodation for rearing insects is still in use at Rothamsted Lodge, and much time is wasted travelling between the buildings. Experimental work is also hampered by the delay in fitting up the constant-environment rooms.

Insect Migration

(R. A. French)

Work has continued on the migration of Sphingidae and other insects in Western Europe. Light traps were worked from April to the end of October, in order to have additional data to compare with Dr. C. B. Williams' finding in Inverness-shire. A further comparison of the results of trapping in different environments on the farm was made with J. C. da Silva Dias.

Gall Midges of Economic Importance

(H. F. Barnes, Barbara M. Stokes and D. L. Milne)

The long-term study concerning the two wheat blossom midges was carried out for the thirtieth successive year. Insectary observations showed that, while 25 per cent of the 1955 *C. tritici* large larval population emerged, the relative parasitism was 22 per cent. In contrast the relative parasitism of the 1955 *S. mosellana* was 97

per cent, while that of the total flight, which only covered the last eight years' populations instead of the previous thirteen, as occurred in 1955, was 73 per cent. Thirty-two per cent of the emerging *S. mosellana* was derived from the 1951 larval population, whereas just under 2 per cent came from the 1955 larvae. Practically 40 per cent of its parasites that emerged in 1956 were derived from the 1953 larvae and 27 per cent from those of 1955, while the remainder came from the larvae of 1950, 1951, 1952 and 1954. On Broadbalk the wet weather enabled the larvae of both species to leave the wheat ears as soon as they had completed their feeding. The adjusted figure for numbers of *C. tritici* larvae was 18,656, as compared with the actual 24,604 in 1955, giving a 7 per cent floret infestation (9·4 per cent in 1955). The number of *S. mosellana* larvae dropped from 2,232 in 1955 to the exceptionally low one of 105 in 1956, the percentage grain infestation being less than one-half of 1 per cent (7·3 per cent in 1955).

The attempt to obtain adults from some of the numerous *Haplodiplosis equestris* larvae of 1955 was unsuccessful. It was observed that very few larvae were present in 1956 on Broadbalk and Hoosfield. But apparently in Yugoslavia this species occurred in sufficient numbers on wheat, barley and rye to attract attention and was particularly injurious to the rye. Likewise in Denmark there were enormous numbers of the larvae in a certain ryegrass seed sample; presumably following a severe infestation of this grass.

On the other hand, adults of the *Contarinia* species on timothy grass inflorescence received from Finland in 1955 emerged in large numbers. At the same time considerable numbers of a *Stenodiplosis* species were discovered ovipositing on this grass at Rothamsted. It is interesting to note that three species of gall midges are now known to cause seed loss in this valuable grass, the third being the *Dasyneura* larva found at Silwood Park in 1953.

Further evidence of the importance of gall midges in grass-seed production was afforded by the fact that Prof. Dr. Muhle sent in for identification from Bavaria a new *Dasyneura* species from *Poa pratensis*. Previously only two species, *Contarinia poae* Tomaszewski and *Sitodiplosis cambriensis* Jones, were known from the inflorescences of this grass.

Experimental work was begun to test the possibility of development of races of *Mayetiola destructor*, the Hessian Fly, more specific to certain host plants than the fly now found at Rothamsted, following the development of strains showing varietal preferences in other countries. This entails breeding " lines " of flies each confined to a single host plant for a number of generations and finally testing them for host-specificity with midges whose host plants have been changed with each generation and with midges from the field. Difficulties have been encountered in maintaining the " lines " owing to the occurrence of unisexual families, but interesting data on this phenomenon are accumulating. The occurrence of Hessian Fly on Broadbalk and Hoosfield wheat–alternate fallow was again estimated.

Work on the life history of *Mayetiola dactylidis* on cocksfoot was continued. Its biology differs from that of *M. destructor* in many respects, and so far it has never been found to interbreed with this

species. *M. dactylidis* has been collected from many localities on Rothamsted farm, but infested cocksfoot shoots are difficult to detect, even when they contain a dozen or more larvae, for the outer leaves bear little sign of damage, although the central leaf tissue is often reduced to a rotting mass.

An interesting new rearing is that of a *Mayetiola* species from the stems of meadow foxtail grass. This was from larval material sent from the Grassland Research Station, Hurley, by Dr. G. W. Heath. Its presence there had been recently established by Dr. I. W. B. Nye. The only previous record is that of larvae found near Aberystwyth by Dr. E. E. Edwards nearly thirty years ago. This species, also subsequently found at Rothamsted by Barbara Stokes, is particularly interesting owing to its possession of a bifid breast-bone.

Further biological evidence was collected supporting the separation of the *Dasyneura* midges found on clover into *D. gentneri*, which normally oviposits on open flowers of white clover but can produce fertile offspring as the result of laying on open red clover, and *D. leguminicola*, which will only oviposit on green heads of red clover. This evidence includes observations on emergence, sex ratio, duration of life cycle, mode of oviposition, larval colour and other biological factors which aid in the determination of the exact taxonomic relationship between two such apparently closely allied species. The attack of white clover by *D. gentneri* was widespread in 1956, and the midge was present in samples from twenty-four counties of England and Wales. Larval observation tubes were set up, and it was found that in both species of *Dasyneura* the sternal spatula or breast-bone is used for moving obstacles when burrowing into the soil and when clearing a space for cocoon-spinning.

Three additional hymenopterous parasites of *D. leguminicola* were identified by the staff of the Natural History Museum, London. These are: *Tetrastichus inunctus* Nees, *Prosactogaster demades* Walker and an *Aphanogmus* species.

The most interesting fact to emerge from this year's studies on clover midges was the discovery of another midge definitely causing seed loss in red clover, and therefore of potential economic importance. This may be *Hadrobremia longiventris* Kieffer, that was previously thought unlikely to be phytophagous. This year, however, large numbers of larvae were present in samples from more than nine counties, and preliminary studies of its biology were made. It is hoped to continue investigations on this species during 1957.

Among the more interesting gall midges received for identification were some reared from fungi by Miss Kitty Paviour-Smith, who is studying at Oxford the community of macrofungi growing on dead and decaying wood; the *Heteropeza* species, swarms of which occurred on the wing in some commercial mushroom houses early in the year, usually only the paedogenetic larvae are to be found; larvae found in the stems of cotton-grass; the larvae from blue tits in pine woods sent by Miss Monica M. Betts, who is studying the food of these birds. From overseas inquiries concerning coccid-eating midges came from Spain, Sao Tome and Jamaica; a sorghum stem midge and a benniseed capsule midge from Mr. K. M. Harris in Nigeria; additional specimens from *Stachytarpheta* in Trinidad

and British Guiana from Mr. F. D. Bennett in connection with the biological control of this tropical weed; and midges found in New Zealand on *Boronia* from West Australia. Further acquisitions for the collection include specimens of the recently described genus and species *Kittada coimbatorensis* Agarwal, *Miastor americana* Felt and *Schizomyia impatientis* O.S.

Mr. W. Nijveldt, on the staff of Instituut voor Plantenziekten-kundig Onderzoek, Wageningen, spent two weeks studying the aphid-eating gall midges in the collection.

Wheat Bulb Fly Studies

Host plant selection (Barbara M. Stokes)

Observations on the possible preferences of wheat bulb fly larvae among its various host plants were continued in pot experiments.

New methods for studying the ways in which newly hatched larvae find their host plants have been tried in the laboratory with promising results. In a series of experiments larvae moved into cubes of alginate jelly taken from a petri-dish in which wheat had been grown, although they contained no part of the plant, and showed no such response to similar cubes of jelly taken from dishes in which no wheat had been grown. Work on larval responses to various stimuli and on the constitution of the substance in the wheat jelly is being continued and extended.

Field studies on oviposition, emergence and survival (F. Raw, R. M. Dobson, J. W. Stephenson and J. R. Lofty)

The experiment on Broadbalk, to estimate the effect of infestation on yield by screening strips of plots to prevent oviposition, is being repeated. On the fallow section of plots 2, 3, 5, 7 and 10 two strips each 6 feet wide and running the width of the plot were screened with mosquito netting during the oviposition period. At harvest 1957 the yield from these strips will be compared with that of similar unscreened strips to give an estimate of the effect of infestation on yield.

A new technique, combining the use of a large field emergence cage with the method of marking and recapture, has been developed to facilitate field studies of populations of wheat bulb fly adults. The cage, 24 feet long, 12 feet wide and 6 feet high, was made of terylene netting on a light metal framework and had very little effect on climatic conditions inside it. It was set up in an infested wheat field shortly before the flies emerged and was searched for flies twice daily throughout the emergence period. Newly emerged flies were marked with paint to indicate the date of capture and were then immediately released inside the cage. Marked flies were subsequently recaptured at regular intervals. The data provided information on the following points:

1. Total number of flies of each sex emerging within the cage. This could be related to the numbers of larvae and pupae previously estimated.
2. Rates of build-up and decline of the population of both sexes.

3. The structure of the population in terms of sex ratios and absolute numbers throughout the life of the adults.

Larval studies (D. B. Long)

The continued spring survey of infestations following various crops showed that the population had made some recovery after the drastic reduction in the winter of 1954/55. For example, the population on the wheat and fallow plots which had fallen in 1955 from 1,038,000 to 215,000 larvae/acre rose in 1956 to 583,000 larvae/acre. In general, the greatest infestation occurred in the wheat plots of the six-course rotation experiment with 800,000 larvae/acre involving 55 per cent of the plants at the time of sampling.

The observation made in pot experiments in 1955 that although wheat bulb fly is a major pest in the Fenlands, infestation of wheat was very much more successful on Rothamsted clay-loam than on Fen peaty-loam, was confirmed in 1956. The highest infestation of wheat grown in pots of clay-loam set up at different pH levels within the wheat tolerance range occurred in soils of pH 5·5–6·5. Whilst a lower level was found in alkaline soils up to pH 8, an acid soil of pH 4·9 produced a marked reduction. These experiments, coupled with those using Fen peaty-loam, showed that although the pH factor could influence the infestation, this was not the factor responsible for the very poor infestations obtained with peaty-loams.

From the continued studies on larval movements in soil it appeared that newly hatched larvae move directly upwards towards the surface, restricting their subsequent movements to the top 1–2 inches of soil. These experiments are being continued.

Observations on the adult (D. B. Long)

Field observations on the adult fly were continued, and several previous findings were confirmed. Attempts made to follow the dispersion of flies over Broadbalk throughout the summer were frequently interrupted by bad weather. At first both males and females were found to spread out fairly uniformly from the central emergence section, and their patterns of dispersion over the field coincided. As the season progressed, however, the patterns of dispersion became less coincident as the males congregated towards the northern edge of the field. In general, fly populations appeared to be mostly localized round infested wheat fields.

The earlier finding that flies tended to avoid laying eggs near a vertical screen was confirmed, and observations suggest that this was partly due to an optical effect involving contrasts of light and shade. Experiments have shown that light plays a major part in the maintenance of the oviposition rhythm earlier observed. Light may also be responsible for the much lower level of egg laying that had been found to take place in tall crops such as beans or wheat. An experiment set up on Long Hoos VII to study the oviposition preferences between fallows and stands of wheat at different plant densities proved inconclusive due to the extraordinarily low level of the subsequent infestation; 1·8 per cent of the plants following fallow and 0·09 per cent of plants following wheat being infested.

The site is near to the heavy infestations on the six-course experiment and the wheat and fallow strip, and since flies were known to be in the area, it may be concluded that flies do not lay at random on all available fallow ground.

In the laboratory it has been found that flies tend to lay eggs at intervals and that the rate of egg laying increases with the age of the fly. Most of the eggs obtained were laid by relatively few individuals.

In work begun on nutrition and feeding responses the fly has been found to be most sensitive to the sugars.

A study of pathogenic fungi has been started with E. W. Buxton (Plant Pathology Department).

Aphid Ecology and Insect Dispersal

Periodism and energy summation (C. G. Johnson and L. R. Taylor)

The mechanism of diurnal flight rhythms in *Aphis fabae* and similarly behaving species has largely been solved; and in doing this a principle of wide application to periodic change of a more general nature (e.g. population growth and decline) has been put forward. A rhythmic change in the number of aphids flying off a breeding site during the day depends primarily on a fluctuating source of energy—in this case heat—which, by producing a fluctuating rate of development, also produces as a consequence an alternate increase and decrease in numbers of alatae produced. By a process of energy summation this periodicity can be reconstructed theoretically.

The next step is to extend this principle to the periodic growth of populations in aphids and also in other insects. A start has been made with this : it involves field and laboratory work on the effects of temperature in the duration of development.

Duration of teneral development in A. fabae (L. R. Taylor)

Three important facts have come from a study of the teneral stage of alate *A. fabae* in relation to temperature. First, that the mean temperature of a fluctuation ranging between approximately 7° and 34° C. has virtually the same effect on development time as a constant temperature equal to the mean. This implies that some work formerly done in the laboratory may now be safely done in the field, and vice versa. Secondly, a method of successive approximations in fitting curves of variable field data has been developed which assesses the mean temperature and mean developmental period with great accuracy. Thirdly, the possibility that the temperature-development curve is to be seen as a frequency distribution rather than as a functional relationship (as hitherto) may open up a new theoretical approach to temperature relations in biology.

Flight inhibition in aphids (A. J. Cockbain)

It is known that aphids cease to fly when the temperature falls below a certain value. Using captive flying aphids in a small wind-tunnel, a study has been made of the influences of flight duration and of humidity on this threshold, with *A. fabae*.

It was found that the threshold for wing-beat movement is negatively related to duration of flight and that high humidities are associated with a high threshold, and vice versa.

Vertical dispersal of insects (C. G. Johnson and L. R. Taylor)

This work continues. A general, empirical expression has been found which relates density to altitude for many classes of insect. The mathematical and the vertical aspects of insect diffusion are being studied in collaboration with Mr. J. G. Skellam of the Nature Conservancy.

Much data have been collected on the hourly change in vertical density profiles in relation to atmospheric stability. Detailed analysis of these results proceeds.

Wireworm Populations

(F. Raw, J. W. Stephenson and J. R. Lofty)

The studies of wireworm populations begun in 1950 on the ley and arable rotations in Highfield and Fosters have been concluded. The results, which now cover two complete crop rotations, are being prepared for publication.

Effects of Insecticides on Soil Fauna

(R. M. Dobson, J. W. Stephenson and J. R. Lofty)

The observations carried out by invitation of Messrs. Plant Protection Ltd. on material taken from their field experiment at Haslemere in autumn 1955 are now almost complete. This experiment was designed to study the long-term effects of BHC applied yearly or every fourth year to the soil in a four-course rotation (swedes, barley, ley, wheat), and allows rotational and insecticidal effects to be assessed independently. Field observations were made one year after the last application of insecticide. The rotation caused large fluctuations of soil populations. Collembola increased during the second year and then decreased. Mesostigmata (Acarina) continued to increase until the third year. Both groups were greatly reduced during the fourth year. The BHC treatments caused a general reduction in the numbers of most groups, and sometimes modified the fluctuation caused by the rotation, e.g., on treated plots subterranean Collembola were at their maximum during the third year instead of the second. This group was also exceptional in that the highest populations occurred on the plots treated annually and the lowest on the controls. Mesostigmata appeared to be unaffected by the treatments.

Earthworm Studies

Rehabilitation of marginal grassland (R. M. Dobson and J. R. Lofty, in conjunction with Dr. E. Crompton of Durham University)

The experiments in Lancashire to investigate the rôle earthworms play during the rehabilitation of marginal grassland have continued.

It has not yet been possible to apply the manurial treatments on the Rivington site, but the experiment at Lancaster is proceeding satisfactorily. The operations carried out here so far have been: liming—summer 1954; phosphate and farmyard manure applied—summer 1955; lead arsenate spraying—autumn 1955; grass burning and application of artificial fertilizers—spring 1956; mowing of plots and second application of phosphate and farmyard manure—autumn 1956. A second application of artificial fertilizers will be made in spring 1957.

A survey made in September 1956 showed that the lead arsenate treatment had successfully reduced the earthworm population on the treated halves of the split plots. So far the various manurial treatments show little effect.

Earthworm populations in orchards (J. W. Stephenson)

The effect of repeated applications of fungicides and insecticides on the earthworm population of orchards and the rate of removal of surface litter is being investigated.

Excessive casting by earthworms (J. W. Stephenson)

Reports were received of excessive earthworm casting in an area of Fryupdale, Yorks, where, at harvest, wormcasts were frequently found 12–18 inches high in corn stooks, making it difficult to obtain clean grain when threshing. A brief survey of the area showed a high population of the casting species *Allolobophora nocturna* (Evans). Further investigations will be made in co-operation with Durham University Zoology Department.

Millipede Studies

(J. W. Stephenson)

A method for culturing millipedes using plaster-of-Paris cells with glass plates top and bottom has been developed. The method permits details of copulation, nest building, emergence from eggs and moulting to be observed. Moulds which have been troublesome hitherto do not appear to thrive in the cells.

Studies on Beetles

(R. M. Dobson)

This work has largely been held in abeyance during the past year, but routine identifications of *Carpophilus species* (Nitidulidae) have continued. A field experiment designed to study diurnal rhythms in flea-beetles had to be discontinued due to destruction of the seedlings by birds.

Ecological Studies on the Natural Enemies of Aphids

(C. J. Banks)

Investigations were carried out to examine the evidence that ants, attending aphids for the honey dew they excrete, protect them from the attacks of natural enemies and, at the same time, cause them to multiply more rapidly than aphids which are ant-free. *Aphis fabae*

and the common garden ant, *Lasius niger*, which sometimes attends it, were used in the experiments.

It was confirmed that some predators were attacked and driven away from the aphids on the bean plants by the ants; other predators, including the parasite *Aphidius*, were not attacked. In the absence of the enemies, the aphid colonies tended by the ants sometimes multiplied more rapidly than controls, the results confirming those of some other workers. But in some experiments there was no difference in aphid numbers on ant-attended and ant-free plants, a problem which will be investigated during 1957.

Experiments were also started to assess the effectiveness of various species of predators of *Aphis fabae*. Numbers of predators were put on to caged bean plants infested with known numbers of aphids; another cage with equal numbers of aphids on similar plants was used as control. A comparison of the aphid numbers remaining on the two sets of plants gave an estimate of the numbers of aphids destroyed by the predators, and the results could be compared with those from experiments in which other predator species had been used.

Late-stage Coccinellid larvae were very effective in quickly destroying the bulk of the aphids, but the larvae left the plants without having eaten them all; some aphids remained hidden between leaflets at the tops of the plants. Previous studies on the behaviour of these predators had shown that they tend to stay on the plants when there is food readily accessible.

On the other hand, small insects like the Anthocoridae were able to get into crevices and destroy the aphids there, but were unable to eat as large a total of aphids as the coccinellids. Chrysopid larvae, although provided with long piercing and sucking mouth parts, were surprisingly ineffective in reducing aphid numbers. Further work on these and other predators will be continued during 1957.

Control of *Aphis fabae* by its Natural Enemies

(C. J. Banks)

To supply much-needed quantitative information on how entomophagous insects affect the numbers of an aphid pest like *A. fabae*, experiments were started in the spring of 1956 in collaboration with M. J. Way of the Insecticides Department.

Natural populations of the aphid and of its insect enemies are being studied on the winter host-plant (*Euonymus europaeus*) and on the summer host-plants (beans and *Chenopodium*); also, caged plots of these plants were artificially infested with equal numbers of the aphids at various times throughout the spring and summer. From one type of cage entomophagous insects were excluded by dieldrin-treated terylene netting; in another, parasites and predators entered the cages between slats on the walls which were adjusted to give climatic conditions comparable to those in the other type of cage. Sticky traps were set up in the localities studied to give estimates of the abundance of flying predators and aphids during the year. The caged plots, from which predators were excluded, developed much larger aphid populations than the plots where the insect enemies were free to enter.

Natural populations on *Euonymus* in spring were very small, and comparatively few alatae migrated to beans, where only small infestations developed, in contrast to the heavy artificial infestations in the cages. Populations of predators remained low in number and were unable to multiply on the few aphids on beans and, later, on *Chenopodium*. In November and December fair-sized populations of the aphid developed on *Euonymus* once more and there laid eggs. If insect enemies play an effective rôle in the complex life cycle of the aphid it is possible that a large population of aphids will develop during 1957, and this in turn should allow predators once more to multiply rapidly.

Effects of Population Density on Insects

(D. B. Long and M. A. Zaher)

Experiments have been carried out on the effects of the larval population density on adult Lepidoptera. The species used were *Plusia gamma* and *Pieris brassicae*; experiments with the cotton leaf worm *Prodenia litura* being terminated by latent virus infection.

Adults from crowded larvae are generally smaller in size and weight than their solitary counterparts; there are also differences in the ratio between the length of the fore-wing and the hind femur (the ratio of wing to femur length is greater in crowded than in solitary forms) which reflect effects previously observed in larval development.

It has also been observed that at the end of their development crowded larvae had a higher fat content than the solitary controls, and it has now been found that the situation in the resulting freshly emerged adults is reversed, with the adults from crowded cultures having less fat. These adults, however, had a higher glycogen content. Experiments have shown that adults from crowded cultures consume less food and yet live a longer time than their solitary counterparts. These results suggest a difference in the utilization of the food reserves, and further analyses to elucidate this problem are being carried out. Eighty per cent of the daily total of food consumed by *P. gamma* was taken at dusk and dawn, when the moths were most active.

Observations on oviposition periods and fecundity are in progress. The eggs laid by adults from crowded larval cultures were the lighter in weight.

The population density of the adults was found to produce marked effects. As the number of pairs of moths per cage was increased, the mean total eggs laid per female also increased. A large part of the maximum increase observed could be obtained by increasing the number of pairs from 1 to 2, when the total eggs laid per female rose by 70 per cent. It was also found that the pre-oviposition time was reduced by increasing the number of pairs such that cages containing 8 pairs took less than half the time taken by single pairs. Other aspects involving longevity and the egg-laying rate are being investigated.

Forest Soil Investigations

(P. W. Murphy)

During the present year experimental investigations have been concerned with the fauna associated with freshly-fallen tree litter. There is increasing evidence of a sequential pattern in organic-matter decomposition with a succession of fauna and flora associated with it. Present studies are directed to this aspect in order to determine whether in fact successional biological phases occur in decaying leaves, and if so the species associated with each stage. A major problem in these investigations is the difficulty of ascertaining the age of leaves used as experimental material. A partial solution would be to collect recently fallen leaves, but the difficulty here is to maintain these in conditions comparable to those occurring in the natural milieu. The possibility of marking leaves with a radio-active isotope is being explored, and a pilot experiment using this technique was commenced in the autumn of the present year. Beech leaves were marked on the trees with an artists' oil-colour to which had been added tantalum 182. Preliminary results suggest that this technique is a promising means for recovering leaves of known age, but the effect of the isotope on the living inhabitants of the leaves has yet to be ascertained.

A study of predators of cysts and adults of *Heterodera cruciferae* was made with C. C. Doncaster of the Nematology Department. Field observations of rape seedlings in a plot in which *H. cruciferae* had been cultured for about seven years suggested that the nematode population was being reduced by unknown predators. Using a laboratory culture technique, it was found that certain members of the soil meiofauna, especially the springtail *Onychiurus armatus*, fed upon cysts and adults of *H. cruciferae* and other nematodes. The results of this investigation will be published shortly. This sintered-glass culture cell was also demonstrated at a Conversazione of the London branch of the Institute of Biology.

Insect Pests at Rothamsted and Woburn

(R. A. French and K. Mellanby)

Outbreaks of insects which might cause damage have been investigated on the farms on experimental and non-experimental crops; where it seemed possible that experimental yields would be affected by insect attack, this was reported as early as possible to the scientific worker concerned. No really damaging infestations occurred during 1956. Frit fly did some damage to oats, particularly in Pastures, and a very high population of adults emerged in the granary after harvest. Experimental potatoes in Great Knott III were endangered by wireworm (1,000,000 to the acre), but aldrin applied by the farm staff gave good control. Lucerne in Great Harpenden I was seriously attacked in the early stages by millipedes. The damage was particularly noticeable because the cold, dry weather slowed the growth of the crop. It is hoped to continue and extend this survey next year.

Insects and Climate

Effects of climatic factors on metabolism and behaviour (K. Mellanby and R. A. French)

Plots of brussels sprouts were grown on Bones Close and Furzefield in positions where substantial microclimatic differences were expected to occur. Temperature records were kept by the Physics Department. The growth of large cabbage white caterpillars was investigated on these plots. The weather during the experimental period (August and September 1956) was such as to minimize microclimatic differences, and the results obtained from the insects were inconclusive. Further experiments are planned in the same locations.

Laboratory experiments on mealworms and other insects have been continued, partly to provide material for the analyses described below. Factors influencing activity have been investigated (a paper was read to the Association for the Study of Animal Behaviour in October). It has also been shown that changes in diet may substantially alter the position of the optimum temperature for development, and may extend the range over which survival is possible.

Fat Metabolism and Temperature

(L. M. Cherry and K. Mellanby)

Much time has been spent on improving techniques for extracting fat from insects and for determining its iodine number and other characteristics. It appears that imperfections in methods must substantially reduce the value of much of the earlier work on insect fat. Work is proceeding on the analysis of fats from insects reared at, or acclimatized to, different temperatures, and also on the effects of differences in diets on the composition of fat reserves.

BEE DEPARTMENT

C. G. Butler

General

During 1956 the work of the department has largely followed the lines which have been outlined in previous reports. Several members of the department have lectured to Scientific Societies, Research Groups, Beekeepers' Associations, etc., and have taken part in Summer Schools and similar short courses; they have also continued to serve on various committees, such as the Ministry's Bee Disease Advisory Committee.

During the year J. Simpson was awarded the Ph.D. degree of London University, and C. R. Ribbands resigned in order to take up an appointment as Lecturer in Crop Pests in Cambridge.

Bee Behaviour

Swarming

J. Simpson has continued his work on the factors controlling the incidence of swarming by honeybee colonies. Some of the results of the work have already been mentioned briefly in previous reports, and full accounts of these have now been prepared for publication.

Further work led to the conclusion that if colonies of bees were given adequate space in their hives, and were not interfered with in any way, the proportion which would swarm is probably between 10 and 40 per cent.

The numbers of colonies which swarm become smaller in the latter part of the summer in a way which cannot be related directly to seasonal changes in environmental conditions. Much of this reduction is probably due to exhaustion of the supply of colonies capable of swarming. An examination of the records of colonies which began to rear queens but did not complete the process provided little evidence that the tendency of colonies to rear queens diminished in the latter part of the summer in any way which could not be directly related to the seasonal reduction in length of day, temperature and availability of nectar. On the other hand, dissections of worker bees in 1954 showed that there was a seasonal trend in the size of their fat-bodies, which continued in the same direction from May until October, thus suggesting the existence of a physiological change which has no direct relationship with environmental conditions.

In this connection Simpson has also made comparative studies of the salivary glands of worker bees, both in and out of the swarming season. He has been attempting to determine the nature and function of the secretions of these glands, in particular of the post-cerebral and thoracic ones, about which little is known. He has found that the post-cerebral and the thoracic glands contain both oily and watery secretions, the two phases being clear, homogeneous

and distinct. Previous workers have failed to find any invertase, diastase or protease in the secretions of either gland, which Simpson has shown in each case to be slightly acid (about pH 6). The oily contents of the secretions of these glands stain with Sudan III and readily dissolve in ether or chloroform, but not in alcohol or in acetic acid. They appear to be largely unsaponifiable. The quantity of oily material present in these secretions varied considerably from bee to bee. The glands of some contained no detectable amount, but most had at least a little; many bees had large amounts in their post-cerebral glands, but only a few had much in their thoracic glands.

In summer large amounts of this oily material were much more frequently found in the post-cerebral glands of bees caught whilst foraging than in those of bees taken from their hives.

Attempts are also being made to compare the properties of the saliva discharged by bees under various circumstances with those of the secretions of the various salivary glands. So far it appears that when saliva is used by bees to dissolve dry sugar this saliva is either neutral or only very slightly buffered and contains no invertase or reducing sugars. Such saliva might, therefore, come from either the post-cerebral or thoracic glands, but could not come from the mandibular glands, whose secretion is strongly acid, nor from the pharyngeal glands, whose secretion contains invertase, nor by regurgitation from the honey-stomach because its contents contain acids, invertase and reducing sugars. Filter-paper which bees had chewed was found to be distinctly alkaline (pH 8–9), although none of the salivary glands are known to produce alkaline secretions.

Simpson has observed that a strong scent, which several workers have found to be associated with the contents of the mandibular glands, occurs chiefly in the glands of foraging bees.

In view of the work of de Groot and Voogd (*Experientia*, 1954, **10** (9), 384), in which they demonstrated that queen substance is more abundant on the head of a queen than on other parts of her body, Simpson has suggested that this important substance may perhaps be secreted by the mandibular glands, which are much larger in the queen than in the worker. A preliminary experiment by C. G. Butler to test this hypothesis failed to yield a positive result, but further tests with an improved technique are being undertaken.

The transmission of food between adult worker honeybees

J. B. Free has obtained further information on the distribution of food throughout a colony by recording the passage of food between marked worker bees of known ages. He has found that day-old bees seldom feed other bees, and that two day-old bees do not give food as frequently as older bees. During the early part of adult life worker bees receive food more often than they give it, but as they grow older they tend to give it more frequently than they receive it.

As bees grow older the mean age of the bees who feed them increases; as does the mean age of the bees they themselves feed. In general, bees tend to receive food from bees older than themselves and to give it to bees younger than themselves. Thus there

is a general tendency for food to pass from older bees, many of whom are foragers, to younger bees who feed the brood. However, bees of all ages are fed by, and feed, bees of a wide range of ages. It is most probable, therefore, that food, and any substance it may contain, such as social hormones, are passed freely around the colony between bees engaged in different duties.

Although bees which are about to feed other bees generally have more food in their honey-stomachs than those who are about to receive it, the quantities of food contained in the honey-stomachs of bees belonging to these two categories overlap considerably. Several factors may influence the result. For example, the food-offering behaviour of bees which have recently licked their queen, and so obtained queen substance, is not governed by the amount of food in their honey-stomachs. Bees undertaking certain duties may more readily retain food than those occupied with other duties. From a study of the behaviour patterns associated with food transmission it appears probable that those bees who require relatively large amounts of food in connection with wax or brood-food secretion can stimulate bees with little food to feed them, and, similarly, bees with full honey-stomachs (e.g., successful foragers) are sometimes able to stimulate bees which already contain a lot of food to accept more from them.

The quantities of food which different bees contain when they show themselves willing to give or receive food may well also depend on their past experience, since it was found that improvement or deterioration in the attractiveness, as well as in the quantity, of syrup fed to bees had a marked effect on the amount retained in their honey-stomachs. These results probably account for the fact that a much closer correlation between a bee's behaviour in respect to food transmission and the amount of food in her honey-stomach is obtained with recently emerged, unconditioned, bees than is obtained with bees of all ages taken at random from their colonies.

Queen supersedure

C. G. Butler has continued his studies on the process known as "queen supersedure", by means of which the worker bees of a colony replace their queen by a young one without swarming.

Many suggestions have been made in attempts to explain the initiation of this process, such as: disease of the queen; her inability to supply her colony with "sufficient" eggs either on account of old age or injury; the production of an abnormally high proportion of drones; failure of the queen to supply sufficient queen substance—and these have been investigated.

It has been possible to demonstrate that a queen can still inhibit worker bees from rearing further queens, even though she is not producing any eggs externally. Nevertheless, it was found that young virgin queens do not always inhibit queen rearing by the workers of their colonies, which cannot be explained by the fact that they are not producing any eggs. It was also found that queens which were laying drone-producing eggs only were often fully capable of inhibiting queen rearing; and it was demonstrated that a queen, who had actually been superseded by her workers, was nevertheless capable of inhibiting queen rearing in small, but not in large, colonies.

As it has been shown previously (Butler (1954), *Trans. R. ent. Soc. Lond.* **105**, 11) that a substance which worker bees obtain from their queens (queen substance) inhibits them from rearing further queens, provided that the quantity is sufficient for the number of bees present in their colonies, it is probable that this queen was producing insufficient queen substance to inhibit queen rearing in a large colony.

It was concluded that shortage of queen substance is the only immediate cause of queen supersedure, and that any other factors which tend to initiate this process do so by reducing the queen's output of this substance. A paper giving a full account of this work is being published.

Queen substance

Further work on the nature of queen substance and on its collection and distribution by the members of a colony has been carried out by C. G. Butler, who has shown that, despite suggestions to the contrary (Voogd, S. (1956) *Experientia*, **12**, 199), the queen substance which worker bees receive in regurgitated food from other workers, who have either obtained it directly by licking their queen or indirectly from other workers, is sufficient to inhibit development of their ovaries in the absence of a queen of any kind. However, it has become clear that a greater degree of ovary inhibition is obtained when an extract of queen substance is placed on the body of a dead worker bee, to which the experimental bees have free access, rather than in the food of the latter. This has resulted in an improvement in the technique of testing the efficacy of extracts from queens, etc., and various other substances, as inhibitors of ovary development in queenless worker honeybees.

In preliminary experiments it has been found that small quantities of both androsterone and testosterone (kindly supplied by Dr. R. K. Callow of the National Institute for Medical Research), when fed to worker honeybees, inhibit development of their ovaries under conditions in which they would otherwise develop. Materials extracted in acetone from the bodies of mated queen wasps (*Vespula germanica*) and mated queen ants (*Formica rufa* and *F. fusca*) have also been found to have similar inhibitory effects on ovary development to those obtained with honeybee queen substance when given to queenless worker honeybees; but extracts obtained from mated queen bumblebees failed to produce an inhibitory effect.

General Research

Ovary development in worker bumblebees

J. B. Free has continued his study of egg-laying workers in bumblebee colonies. He has shown that the ovaries of workers kept singly or in small groups at low temperatures do not develop as much as those kept in the same way at higher temperatures. However, the degree of ovary development of the bees in the larger groups was similar at all the temperatures used. It seems possible, therefore, that in these larger groups the body temperatures of the individual bees are raised so that the retarding influence of cold on ovary development is no longer operative.

Nevertheless, the number of bees forming a group has an influence on the development of the ovaries of the members of the group when temperature ceases to be a limiting factor. Within limits the extent to which the ovaries of worker bumblebees develop increases with the size of the group. It is possible that this effect of group stimulation of ovary development is related to differences in the amount of food consumed by individuals belonging to groups of different sizes. However, even when worker bumblebees are kept in isolation their ovaries sometimes develop sufficiently for them to lay eggs.

The defence of bumblebee colonies

J. B. Free has studied the ability of bumblebees to recognize bees from other colonies as intruders. Bumblebees are able to recognize intruders by their scent alone in the same way as honeybees can. It seems possible that the distinctive odours of bumblebees from different colonies are partly genetical in origin and partly due to absorption of nest odours on the waxes of their body surfaces.

Guards are often present at the entrances to the nests of large colonies, but, although no guards are present in the case of a small colony, certain of its members are more ready to attack intruders than others. The degree of aggressiveness shown by individual bees appears to be related to the degree of development of their ovaries. This association between ovary development and ferocity also probably explains the hostility which queen bumblebees show towards each other. Free has suggested that the fact that the ovaries of all but one of the members of a bumblebee colony normally remain relatively undeveloped is of considerable importance in maintaining peace in the colony.

Bee Diseases

Nosema disease

L. Bailey has continued his work on Nosema disease. In late April 1956 he found that there were only 11 colonies at Rothamsted, out of a total of 250, which were infected with this disease. One of these had 18 per cent of its bees infected, but the rest had less than 5 per cent infected. The original general infection has obviously dwindled, almost to extinction, as the result of fumigation of all combs with the vapour of acetic acid, thus killing all Nosema spores on them (see *Report Rothamst. exp. Sta. for* **1953**, **1954**, **1955**).

An experiment is now in progress to see if Nosema infection can be eliminated from colonies by fumigating all their combs, except those containing brood, in spring, and returning them to the colonies directly after fumigation is complete—i.e., after about one week. It is thought that the small number of brood combs remaining untreated may be cleaned sufficiently by the bees, who use them repeatedly during summer, to eliminate any residual infection. This method, if successful, will avoid the labour of transferring colonies completely to fumigated combs, and is likely to be more attractive to commercial honey farmers possessing large numbers of colonies.

Acarine disease

L. Bailey and Elizabeth Booth (*née* Carlisle) have, by marking in the autumn of 1955 all the bees of a colony infected with acarine disease and then taking periodical samples from them, shown that the percentage of infected individuals in this colony remained constant until about March, after which it declined slowly but significantly. This indicates that the infected bees were dying more quickly than the non-infected ones. In the case of a lightly infected colony this would be unimportant, but in the case of a heavily infected colony it would lead to a serious reduction in strength. This experiment is now being repeated with heavily infected colonies.

From mid-April onwards infection of the unmarked bees in the experimental colony mentioned above began to increase from 4 per cent at the constant arithmetical rate of about 20 per cent per month. This increase ceased shortly after the first period of intense activity of the colony, in May 1956, during a honey-flow; but it recommenced at the same rate when the honey-flow failed in June and continued until the end of August. Between June and September no honey-flow occurred, and infection of the bees reached 90 per cent. Although less-detailed observations were made on them, it became clear that infection followed a similar course in all the other colonies suffering from acarine disease.

In 1955, when the weather in summer was consistently good, a similar rate of increase of infection occurred from about April onwards, but it ceased and then continued to decrease after late May.

It seems, therefore, that suppression of infection is associated with high colony activity; hard-working, infected bees probably die off quickly, and there may be a partial separation of the older more infected bees from the newly emerged ones which have not yet become infected and which are known to be susceptible to infection only during the first few days of their lives.

European Foul Brood

The isolation in pure culture of *Streptococcus* ("*Bacillus*") *pluton* has now been accomplished by L. Bailey, who has published a short account of his work giving details of the medium employed (175). He has shown that both *S. pluton* and *Bacterium eurydice* have to be present together in a larva to cause European Foul Brood disease.

S. pluton is normally an anaerobe, but until recently *B. eurydice* was considered to be an aerobe or microaerophile. It is now evident, as a result of Bailey's work, however, that *B. eurydice* grows equally well, perhaps even better, as an anaerobe if fructose and glucose are both present in the medium : honey has the same effect. Anaerobic growth with any concentration of either fructose or glucose alone is feeble. The simultaneous growth of *S. pluton* and *B. eurydice* within the larval gut, in what are presumably anaerobic conditions, thus now becomes understandable.

The metabolic pathway of fructose would appear to be different from that of glucose in *B. eurydice.* The growth of *S. pluton* is the same with glucose or fructose or both these sugars together.

Bailey has obtained complete control of this disease by feeding quaternary ammonium compounds in sugar syrup to infected colonies in the autumn. Signs of reinfection returned as usual during the following season in control colonies, but no trace of this disease was found in the treated colonies, which were inspected at frequent intervals throughout the season. Dilutions as low as 1 part in 150,000 of di-*n*-decyldimethylammonium bromide fed in 3 gal. of syrup eliminated the disease from a colony which had suffered a most severe attack. The untreated control colony, which was derived from the same stock before treatment began, was almost annihilated by the disease.

These compounds are not toxic to bees until concentrations greater than 1 part in 15,000 are fed, and the effects on colonies which have overwintered with this concentration in their food stores has been exceedingly slight.

Large-scale trials are now in progress with this form of treatment, and results should become available towards the end of 1957.

In laboratory tests both *S. pluton* and *B. eurydice* have been found to be very sensitive to dilute solutions of quaternary ammonium compounds.

These compounds exert most of their effect in colonies by killing the dormant bacteria on the comb and in the stores during the winter. The disease is suppressed if these compounds are fed in syrup to infected colonies during the summer, but the effect is not permanent.

STATISTICS DEPARTMENT

F. YATES

Two members of the scientific staff left during 1956. Averil M. Munns resigned on marriage, and A. W. Whitwell left to take a post with the United Steel Companies Ltd., Rotherham.

New appointments were : Joan Anderson from the Sheep and Wool Branch of the Queensland Department of Agriculture and Stock and O. B. Chedzoy from the English Electric Company Ltd., Kidsgrove, Stoke-on-Trent. D. J. Knight was transferred from the employment of the National Research Development Corporation to Rothamsted staff.

Fifteen temporary workers were accommodated during the year, six of them from various countries of the Commonwealth.

The Agricultural Research Council Statistics Group at Cambridge has now been placed under the technical supervision of the Rothamsted Statistics Department. Members of the unit are working in close collaboration with the staff of the Department, and are making increasing use of the facilities provided by the electronic computer.

THE ELECTRONIC COMPUTER

The electronic computer has continued to give good service, and its versatility is steadily being increased, both by improvements in the ancillary equipment and by additions to our repertoire of programmes.

The high-speed tape reader (Ferranti Mark II) has now been in service for three months. A new fast-input programme enables this reader to take in tape at about 130 characters per second, compared with the 35 characters per second of the old reader. Initial difficulties with the new reader have now been largely overcome. The parity checked code and control system installed last year has been of immense value in detecting reader errors.

A punched-card reader, which enables the machine to read data direct from Hollerith cards, has been linked to the computer. This consists of a summary tabulator chassis modified to give the necessary input information and control signals. The information on cards, being punched in the conventional manner, has to be converted into binary form by the machine. This has set an upper limit of 100 cards per minute on the input speed, and the present input programme is designed to read in and convert a maximum of 27 columns of a card into binary form at this speed. The input programme includes a check on possible reader errors.

During September the disc store was returned to Elliott Bros. for overhaul and respray. The bearings were checked, and no measurable wear was found. The reading heads were all found to be in good condition. After removing the old coating a new, slightly harder and thicker coating was sprayed on the disc. This has resulted in improvement of the head characteristics, and the

performance of the disc since the overhaul has been very satisfactory. It was hoped at the same time to increase the storage capacity of the disc, but this did not prove possible.

Experience has shown that the double triode valve, which is extensively used in many modern computers, especially in the logical circuits, has a much shorter life, 1,500–2,000 hours, when used in this way than that obtained when used in conventional ways (10,000 hours or more). The valve manufacturers are investigating the causes for this premature failure, and one firm has produced a double triode with a special cathode. At the request of this firm we are at present running a life test on these valves, using a standard form of valve as control. After 1,600 hours' running 37 per cent of the control valves and 5 per cent of the test valves have failed.

The advent of the electronic computer has naturally resulted in a large increase in the volume of numerical work that has been undertaken in collaboration with scientists at other research institutes and experimental stations. The more interesting items of this type are mentioned in subsequent paragraphs of this report.

In April, owing to increasing demands on machine time, a more detailed form of log-keeping was introduced. The analysis of these figures for the period April–December is given in the accompanying table.

Record of machine operation over the period 1 *April–*31 *December* 1956 *

Details of operation	Hours	Percentage
System modification (M)	94·3	5·3
Scheduled maintenance (S)	208·8	11·7
Unscheduled maintenance (U)	46·7	2·6
Programme checking (C)	574·5	32·1
Production runs (P)	757·4	42·3
Abortive efforts (A)	47·8	2·7
Idle time (I)	58·4	3·3
Total machine hours (T)	1787·9	100·0
Normal equivalent working hours (N)	1416·0	

Total time as percentage of normal laboratory time $= \frac{T}{N}$ = 126·3%

% availability $= \frac{C+P+I}{T}$ = 77·8%

% efficiency $= \frac{C+P+I}{T-S-M}$ = 93·6%

% usage $= \frac{C+P}{C+P+I}$ = 95·8%

* This excludes the period 28 August to 9 October, when the disc store was removed for examination and respray. During this period the punched-card reader was linked to the machine, but no details of time spent on this modification were kept.

It will be seen that the machine is now working substantial amounts of overtime. Now that the machine is capable of reading

data from punched cards we expect that the demands on it for productive work are likely to increase substantially, and it is probable that systematic shift working will have to be organized.

Computer Techniques

The Automatic Programming Routine mentioned in the 1955 Report has been further revised and improved and a brief description published (206). It has now proved itself to be an exceedingly useful programme. It was used, for example, in the construction of a programme for the analysis of 2^n factorial experiments. This programme deals with all types of 2^n designs (and also those including factors at 4 and 8 levels) with up to 128 plots. Total and partial confounding, fractional replication and estimation of error from high-order interactions can be simply dealt with. (There is, for example, no need to specify which degrees of freedom are actually confounded.) A simple extension of the programme provides for the analysis of 8×8 quasi-Latin squares. The whole programme contains about 800 orders. A similar programme for 3^n designs is being developed.

Papers on various applications of electronic computers have been prepared. Lipton (198) discussed various practical applications of the computer, summarizing our experience up to the middle of this year. In a further paper (199) he has described two programming techniques of particular use with the one-plus-one address code that is used in several machines employing a magnetic drum store.

The routine analysis of the results of field experiments forms one of our major production tasks on the computer, and Yates, Healy and Lipton have prepared a paper describing the techniques developed for this purpose (205).

Experimental Design and Analysis

Garner, Patterson and Warren have completed the analysis of the results of the four-course rotation experiment at Rothamsted on organic manures and forms of phosphate. Patterson has also prepared a paper on the statistical aspects of this analysis (201). The examination of the results obtained so far on the Woburn ley–arable experiment has been carried out by Boyd and Dr. H. H. Mann, and a paper has been prepared.

Boyd, Garner and Haines completed the examination of the large series of sugar-beet experiments carried out from 1933 to 1949, and a full report has been prepared (187). Boyd has also prepared a further paper dealing with the economic aspects of the manuring of sugar beet (188).

Lessells has completed a summary on the effect of nitrogen on cereals (191).

We have continued to work in close collaboration with the National Agricultural Advisory Service in the design of both crop and animal experiments. As during last year, the electronic computer has been extensively used in the analysis of experiments of

standard design. The following table shows the numbers dealt with (each variate analysed being reckoned as one unit) :

	Randomized blocks and split plots	Latin squares	3^3	2^n
Rothamsted, etc.	365	271	—	13
National Agricultural Advisory Service	544	53	147	40
National Institute of Agricultural Botany	268	—	—	—
Total	1177	324	147	53

A report on an experiment on diets for laying fowls by Mr. I. W. Rhys, Mr. S. Culpin, Mr. G. E. Forsyth and Westmacott (202), and one on experiments on the feeding of penicillin to pigs (Westmacott and Whitwell 204) have been prepared.

Lessells has analysed the month-to-month variation in the results of soil analyses. A report on this topic has been presented to the Closed Conference of Soil Chemists.

A series of factorial experiments on the inter-relationships of copper, molybdenum and sulphate ions in the metabolism of pregnant and non-pregnant ewes was analysed and interpreted by Leech for the Biochemistry Department of the Ministry of Agriculture Veterinary Laboratory at Weybridge. These results were the basis of a paper presented by Mrs. R. Allcroft at the International Grassland Congress in New Zealand.

Surveys

Ten counties (or part counties) have been surveyed during 1956 in the Survey of Fertilizer Practice, and the analysis of the results is proceeding. Because of the importance which the Soil Chemists attach to obtaining soil-analysis data from random samples of fields in different parts of the country, it was decided to resume the practice of taking soil samples in the course of these surveys. Since 1954 information has also been obtained on the use of weed-killers and insecticides. A note based on the results of recent surveys has been prepared on cereal varieties grown in England and Wales (192), also a further note on the use of weed-killers in England and Wales (190). Observations made on the British potato crop were the subject of a paper given by Boyd to the Operational Research Society (189).

The survey of diseases of dairy cattle has been continued in collaboration with Dr. F. W. Withers and the Veterinary Laboratory at Weybridge. A paper is being prepared presenting the results of two years' work in Wiltshire and Devonshire. The Ministry of Agriculture is planning to extend this work to a nation-wide survey, and the proposed method is about to be tried out on a pilot scale in six counties of England. The analysis of the survey of mortality and wastage in pregnant ewes is now completed, and a paper is being prepared in collaboration with Dr. K. S. Sellers. Leech has also collaborated with Mr. J. W. Egdell and Mr. S. B. Thomas of the

N.A.A.S. in the analysis of the bacteriological data from the Survey of Methods of Milk Production (197).

A start has been made on programming the electronic computer for the analysis of survey data.

Methodology

Healy has devised a direct method for the computation of canonical correlations suitable for an electronic computer (195). This is analogous to the " rotation " technique for the evaluation of latent roots and vectors.

Sir Ronald Fisher has recently developed explicit formulae for the probability integral of Behrens' distribution used in testing the significance of the difference between two means with possibly unequal variance (193). Using these, Healy has computed certain significance points of this distribution for cases when the numbers of observations in each sample are small. These tables will be included in the fifth edition of *Statistical Tables for Biological, Agricultural and Medical Research*.

Entomology

Marjory G. Morris has collaborated with members of the Entomology Department in the analysis of a large experiment on the relative efficiencies of different suction traps.

H. R. Simpson has collaborated with Mr. W. H. Potts of the Colonial Office Tsetse Committee in a study of the possibility of tsetse control by the release of large numbers of male flies sterilized by gamma irradiation (211). Since the tsetse female is believed to mate only once, this should lead to a high proportion of sterile matings. The method has been successfully applied to the eradication of screw-worms in Curaçao. It was required to investigate theoretically the effects of releasing different numbers of sterile males over varying periods so that the practicability of the method could be assessed. A mathematical model of the tsetse population was set up and followed through a number of generations on the computer. By varying the parameters of the model, the importance of the underlying assumptions could be tested and the effects of different release patterns determined.

Genetics

An increasing amount of numerical work with a genetical background is being undertaken on the computer.

Dr. E. C. R. Reeve (Institute of Animal Genetics, Edinburgh) is investigating the effect of linkage and selection in inbreeding. He considers a population inbred by sib-mating in which the homozygotes at a particular locus are selected against, and estimates the approach to homozygosity at a second locus linked to the first. Mathematically, this involves the repeated multiplication of a vector by a 19×19 non-symmetric matrix, the elements of which depend on the closeness of the linkage and on the degree of selection operating. A programme has been worked out which calculates the appropriate genotype frequencies in successive generations and which

also gives the speed of the ultimate approach to homozygosity. This same programme has been modified to deal with the similar problem of assessing the effect of equal linkage of a gene to two pairs of lethals in a sib-mating system. The matrix in this case is only 10×10 (Gower).

Dr. J. W. B. King (Animal Breeding Research Organization, Edinburgh) has obtained a large body of data on pigs from the Danish progeny testing stations. This comprises a number of different measurements taken on litters of known parentage, and it is required to break down the observed variances and covariances into genetically meaningful components. A start has been made on standard punched-card equipment, but this is extremely laborious, and the job is being transferred to the computer now that the card-reader is available. (Westmacott and Cohen.)

Dr. J. H. Renwick (Galton Laboratory) is estimating linkage from a variety of human pedigree data. Even when all phenotypes in a pedigree are known, the genotypes are usually not exactly ascertainable, and the method of analysis consists in determining the probability of occurrence of the pedigree in terms of the gene frequencies and the recombination fraction, and in choosing the value of the latter which maximises the probability. For large pedigrees this is probably beyond the capabilities of our computer, but interesting results have already been obtained from a set of pedigrees involving only two generations. (H. R. Simpson.)

Dr. A. E. Mourant (Blood Group Reference Laboratory) has asked us to fit blood-group gene frequencies by maximum likelihood to a large number of observations from all over the world. The appropriate programme is likely to be of fairly general application. (Healy.)

Colonial Work

The amount of advisory work for Commonwealth workers has decreased since the departure of Hodnett at the end of last year. Six Commonwealth workers have stayed in the Department for varying periods and a number of queries have been dealt with by correspondence by Church and Westmacott, who have taken over the responsibility for this work.

Other Work

Healy and Lipton, with Dr. E. H. Ashton of Birmingham University, have completed a large-scale study of measurements on the teeth of humans and the great apes with a view to clarifying the relations between these groups and the fossil anthropoids recently discovered in South Africa and elsewhere (196). The extremely heavy computations were carried out on the electronic computer.

Gower has collaborated with J. H. Rayner of the Pedology Department in the development of computer programmes for the analysis of crystallographic data. One of these is a general structure factors programme, and another is designed to calculate two-dimensional Fourier syntheses. These programmes have been used to refine a projection of sodium formaldehyde bisulphite.

The programme developed by Rees for the solution of differential equations has been used in collaboration with Dr. R. K. Schofield for the calculation of membrane pressure for a sol of spherical particles (203). Rees has also collaborated with Dr. G. Foster of the London School of Economics in the tabulation of percentage points of a generalized beta distribution which forms the basis for certain tests of significance in multivariate analysis. A paper on this work has been prepared (194), and has been accepted for publication.

Dr. K. L. Blaxter, of the Hannah Dairy Research Institute, and Dr. H. Ruben, Manchester University, have developed a mathematical model of the metabolism of dairy cattle which is intended to form a basis for improved patterns of feeding. The process of fitting the model to observed data is extremely complex, and Lipton is developing a computer programme to cope with this problem so that the adequacy of the model may be assessed.

Leech, with Dr. A. B. Paterson and Dr. P. L. Stuart of the Weybridge Veterinary Laboratory, has investigated the efficacy of routine tuberculin testing of dairy cattle. He has developed a discriminant function which makes the best use of the measured reactions of the cow to different tuberculins (200). He discussed this problem at a meeting of the Royal Society of Medicine and pointed out the importance of the differences in sensitivity of animals of different ages and sexes.

A new edition of *Statistical Tables for Biological, Agricultural and Medical Research* has been prepared and is now in the hands of the printers. Several new tables have been included, notably tables connected with the logit and log–log transformations and a table giving the " product ratio " corresponding to different recombination fractions for the analysis of genetical linkage tests (207).

Yates and Healy prepared a revised statistical section for the third edition of the *Van Nostrand Scientific Encyclopaedia*.

Overseas Assignments

Yates spent two months in the early part of the year in Calcutta and New Delhi on a Technical Assistance Mission of the United Nations. Healy spent seven weeks in the United States and Canada on a grant from the Rockefeller Foundation visiting statistics departments and electronic computing centres. During the trip he took over the secretaryship of the Biometric Society from Dr. C. I. Bliss. Church has been seconded for a year to the Food and Agriculture Organization of the United Nations to work in Ethiopia on a Technical Assistance Mission. His main task is the initiation of agricultural surveys.

Conferences, Lectures, etc.

Healy gave a course in statistics for post-graduate workers in biological and agricultural sciences at the University of Nottingham School of Agriculture. Boyd attended the 19th Congress of the International Institute for Sugarbeet Research held in Brussels in February and also the International Potash Congress in London in

August, where he gave a paper on the effect of potash on crop yield (186). Rees gave colloquia at Imperial College and the London School of Economics on electronic computing in a statistical department. Healy attended the meeting of the British Association in Sheffield and gave a paper with Dr. J. M. Tanner on the genetics of human morphological characters (185). He also contributed to a symposium on the philosophy of experimentation at the Royal Statistical Society Study Group. Lessells gave a lecture on the use of fertilizers on grassland at a Refresher Course for officers of the Yorkshire and Lancashire Province, National Agricultural Advisory Service.

FIELD EXPERIMENTS SECTION

The following members of the staff, who constitute the Field Plots Committee, are responsible for planning and carrying out the programme of field experiments: F. Yates (Chairman), H. V. Garner (Secretary), F. C. Bawden, G. W. Cooke, H. H. Mann, J. R. Moffatt, R. G. Warren and D. J. Watson.

Four Working Parties prepare material for the Plot Committee: Classical and Long-period Experiments (Chairman F. Yates), Pathology Experiments (Chairman F. C. Bawden), Agronomy Experiments (Chairman D. J. Watson) and Field Methods (Chairman R. G. Warren).

The number of experimental plots carried out at Rothamsted and Woburn in 1956 were:

	Grain	Roots	Hay	Grazing	Total
Classical experiments:					
Rothamsted	162	14	48	—	224
Woburn	—	—	—	—	—
Long-period experiments:					
Rothamsted	514	392	191	96	1,193
Woburn	133	314	107	12	566
Annual experiments:					
Rothamsted	610	363	112	—	1,085
Woburn	162	128	—	—	290
Total	1,581	1,211	458	108	3,358

Some of these plots were put down for observation only, but 3,134 were harvested and weighed. In addition, some 390 microplots were carried out at Rothamsted, mainly on phosphatic fertilizers and fertilizer placement, but including a set of reference plots showing the effects of nutrients and dung on a series of farm crops. The Garden Plots Committee were also responsible for 210 small plots, mainly on plant pathology problems. At Woburn H. H. Mann had a number of observation plots on exotic crops.

The weather as it affected agricultural operations is described in detail in the farm report; the following brief notes put on record the main features of 1956 to give a general background for an account of the year's experiments.

The main characteristics of the season were a favourable autumn and early winter, followed by an exceptionally cold February which gave excellent spring seedbeds. A spring drought then set in, affecting grass and seedling roots. The dry weather broke in mid-June to give a wet hay-time, followed by the most unpleasant August and early September for many years. The late harvest, with much poor-quality grain, will long be remembered. The weather then improved: there was good weather for potato lifting, and a dry, rather mild period from November to mid-December particularly favourable for clearing the mangolds and sugar beet. In spite of the lost time in late summer, the year finished with work well forward.

Broadbalk

The wheat was drilled on 2 November in a seedbed that was rather firm and sticky after the heavy rain of a fortnight before, consequently in the lower parts of the field the grain did not cover very well under the harrows. Nevertheless, a good plant was obtained, less good perhaps on the section immediately after bare fallow, especially on Plots 10 and 11, which are without potash. Growth was good in the rather dry, warmish weather of early winter, but the crop looked very brown and scorched during the continuous frost of February. It made a very good recovery in March and April, however, and there was promise of a good crop. The wet weather which started in June favoured weed growth, particularly where the treatments produced only light crops. Thistles (*Cirsium arvense*) were very conspicuous on the West end of the field, so much so that on certain plots in the strip set aside for continuous wheat these weeds had to be hand pulled. On the lower end of the field, near the drain, poppies (*Papaver rhoeas*) and mayweed (*Matricaria inodora*) were beginning to come back in quantity; the former being most prevalent on the section recently limed, the latter on the unlimed section.

Leguminous weeds, *Vicia* and *Medicago lupulina* continued to grain ground, particularly on the plots with minerals but no nitrogen. Plot 5, minerals without added nitrogen, which in recent years has carried a dense growth of leguminous weeds, grew a much better crop than the unmanured wheat alongside. The plots without potash showed a noticeable colour effect from the end of July onwards in the ripening straw. The straw and chaff had a dirty dull-brown colour quite different from the clean yellow of neighbouring plots which were fully manured.

Lodging was more or less general, and the plots looked twisted and miserable towards the end of summer, with much weed growing through. The crop had all to be cut one way in a very late harvest. Eyespot, *Cercosporella herpotrichoides*, was prevalent on Broadbalk, being least severe on the plots immediately after bare fallow. Take-all, *Ophiobolus graminis*, was scattered in sections following wheat, but was not found on plots after bare fallow.

Hoosfield

This field continued to show the good effects of the liming carried out in 1955. The dramatic change in the very acid Plot 5A (NPK annually) noted in the first year after liming, showed even more markedly in 1956. What was quite the worst plot on the field is now one of the best. For the first time the whole field, instead of only part of it, was thoroughly hand-pulled for wild oats. This was because Broadbalk, now nearly cleaned, makes very light work for the pickers, who are now free to concentrate on Hoosfield. The barley was sown in an excellent seedbed and made a good start well ahead of the weeds, which did not show up till late in the season. Harvest was very late, and by then some of the heavier yielding plots, including the dunged plot, were badly lodged. For the first

time since 1951, when parts of the plots heavily infested with wild oats were discarded, the whole produce of every plot was harvested.

Barnfield

With the liming of Barnfield in 1956 the programme for the classicals has been completed. On Barnfield it was only Series A, sulphate of ammonia, and Series AC, sulphate of ammonia plus castor meal, which showed acidity, though on Series C, castor meal, the reserve of calcium carbonate was very small. The liming plan adopted was :

(i) A corrective dressing of 5 tons calcium carbonate per acre applied as ground chalk to Series A and AC only.

(ii) A maintenance dressing to be applied to Series A, AC and C at the rate of 1·5 cwt. calcium carbonate per 1 cwt. ammonium sulphate (23 lb. N) and 0·75 cwt. calcium carbonate per 23 lb. N given as castor meal.

The corrective dressing was applied in spring 1956 before the present crop was sown. The maintenance dressing was ploughed in after the mangolds were lifted, the chalk being given at five times the scheduled rate to last for five years. The TCA (sodium trichloroacetate) spray treatment tested on half plots in 1955 and found to be effective was applied to the remaining halves of the plots in March 1956.

The mangolds made a very bad start on a dry seedbed, and the germination and early growth was clearly related to the plot treatments. The dunged strips carried a good plant, which grew fast and was singled early. Series C, rape cake, which was not acid and in fairly kindly tilth, also gave a plant. Series N, nitrate of soda, lying in the valley and not acid, carried a fairly satisfactory plant. The remainder of the field, possibly still acid and certainly low in organic matter, carried so poor and irregular a stand that on 22 June it was decided to cultivate up all areas that had not been singled on this date. This left the dunged strips and the Series N, nitrate of soda.

Soon after the poor stands were ploughed up the weather broke and a very favourable root season set in, with the result that better yields of mangolds were taken from the surviving plots than for many years. Spraying against twitch was very effective. The dunged plots were almost cleared up, and carried a good crop of mangolds in consequence.

Park Grass

The season was a bad one for the permanent hay plots, the continuous frosts in February followed by the spring drought killed off the plants extensively on the acid plots. Those on which Yorkshire Fog (*Holcus lanatus*) was the main species reclothed themselves with seedlings in the latter part of the season, but the others, less acid and carrying a more varied population, still showed bare patches in autumn. Growth elsewhere was very slow to start in the spring, in fact there was very little growth till early June, thereafter when the rain came there was a flush which resulted in a rather light crop

cut on 11 June. One feature of the wet summer was the large amount of wild white clover in the herbage. This was very conspicuous indeed on plots with mineral manuring without nitrogen, but was by no means confined to these. There was plenty of moisture in the second half of the season; the second cut taken on 19 November was therefore heavier than usual.

Agdell

This field is still being cropped without phosphate or potash. Since the old experiment was terminated in 1951 at the end of the twenty-sixth cycle of the four-course rotation, it has carried three cereal crops with basal nitrogen, and in 1956 the crop was winter beans without fertilizer. The beans made a good start in the autumn and came through the very hard weather in February very well. The residual effects of phosphate and potash applied to roots in the old rotation were plainly visible in the growth of beans. Aphis attack was very slight, and the crop was not sprayed. It was harvested by combine, taking two cuts through each of the original six plots.

Long-period Experiments

Four-course rotation

This experiment, begun in 1930 and redesigned in 1955, carried its final crops in 1956. The potato crop was one of the best grown on this land for many years; wheat was, as usual, poor and barley good. Winter beans were badly thinned in the very hard weather in February and were resown on 12 April. They made very strong vegetative growth, and by waiting till 10 October a very good crop was combine-harvested, with a moisture content of 46 per cent. There was no aphis attack this year. All crops were visibly poorer on the old rock phosphate plots, and potatoes, wheat and barley gave big nitrogen responses and showed the residues of former organic manuring. The four blocks of the old experiment will each be sown with varieties of wheat and other cereals to provide material for the study of footrot diseases in relation to the preceding crops, wheat, barley, potatoes, beans.

Deep-cultivation rotation

The two blocks of this experiment which had terminated after completing their cycle were drilled with barley in 1956. In the spring the barley on certain plots showed a yellowing and browning of the tips of the young leaves which suggested potash starvation. The experimental treatments involve dung and muriate of potash, and on certain plots some poor subsoil has been brought to the surface; big differences in potash status between treatments could therefore be expected. Soil and crop samples have been taken for examination, and the results are to be found in the report of the Chemistry Department.

Deep ploughing for wheat gave an increase of 3·6 cwt. grain above that obtained by ploughing to ordinary depth. Dung applied to sugar beet increased the following barley by 1·8 cwt., seeds hay the third crop by 3·9 cwt. and wheat the fourth crop by 2·5 cwt.

Ley–arable rotations

These experiments have now completed one full cycle on every block. The season was not nearly so good for cereals as 1955, but very much better for potatoes. Excellent yields of potatoes were obtained from both Highfield and Fosters. Winter wheat, the first test crop, was somewhat below average on Highfield, nevertheless it was lodged. This occurred even after cut grass, when the crop was conspicuously poor and weedy and carried very small ears. This failure of cut grass as a preparation for wheat occurs every year on this field, and is now being investigated. In this wet season an extra 2 cwt. " Nitro-Chalk " top-dressing for the wheat was harmful after the leys but beneficial after arable crops. On Fosters, an old arable field, the wheat was not nearly so badly lodged, all leys gave better yields of wheat than the arable sequence, lucerne giving the best result. Extra nitrogen was always needed on this field, for the second dressing of 2 cwt. of " Nitro-Chalk " gave a mean increase of +4·1 cwt. grain. Potatoes, the second test crop, yielded 14·25 tons on Highfield without dung and 17·67 tons with 12 tons of dung. The test of additional phosphate and potash was continued for a second year to study the demands of the various rotations for phosphorus and potassium. Ley was by far the best preparation and cut grass the worst. Doubling the nitrogen and phosphate had little effect, but doubling the potash made a great improvement. After the grazed ley, however, the potash effect was greatly reduced. On Fosters the crop averaged 13·15 tons without dung and 15·39 tons with dung. In the absence of dung, grazed ley was decidedly the best preparation for potatoes, but when dung was given the best yield was after arable crops. Cut grass was again the least effective preparation for potatoes. Fosters was much less dependent on extra potash than Highfield, only after lucerne was the effect of doubling the potash at all noticeable.

The third test crop, barley, was badly lodged but gave good yields. An extra 0·2 cwt. nitrogen was harmful on both fields, for it put the crop down earlier. In contrast to the other test crops, barley did quite well after cut grass, but the grass was ploughed in three years previously in this case. Some of the main treatment effects in the test crops are given in Table 1.

The herbage crops in 1956 gave slow early growth without any marked flush; most of the crops held out well throughout the moist summer and the stock had a longer grazing period than usual. Highfield, on the whole, was faster growing and more productive than Fosters, particularly in the old grass, which stood up well against a full season's grazing with only a break of 2 weeks. The reseeded grasses on both fields carried a high proportion of clover which the sheep did not graze completely. The three-years ley on Highfield was particularly good in its seeding year; the second and third years of the grazing leys were almost as productive as the permanent grass on both fields.

Cut grass gave four cuts in its first year and six cuts in each of the later years. All lucerne looked well, but in mid-September large patches of wilted plants were observed in the third cut of the second- and third-year stands of lucerne on Highfield and to a

TABLE 1

Rothamsted ley–arable experiment: Highfield and Fosters
Yield of test crops, 1956

	After 3 years' cropping with:				
	Lucerne	Grazed ley	Cut grass	Arable crops	Mean
First test crop:					
Wheat, grain, cwt./acre					
Highfield	34·2	36·2	20·4	39·7	32·6
Effect of 0·3 cwt. N ...	−1·1	−1·5	−1·9	+2·9	−0·4
Fosters	41·7	36·1	33·8	30·5	35·5
Effect of 0·3 cwt. N ...	+2·6	+3·0	+3·7	+6·9	+4·1
Second test crop:					
Potatoes, tons/acre					
Highfield	15·64	17·86	14·81	15·54	15·96
Effect of 12 tons dung ...	+5·09	+2·48	+2·85	+3·24	+3·42
Effect of 0·5 cwt. N ...	−0·98	−0·07	+0·13	+0·72	−0·04
Effect of 0·9 cwt. P_2O_5 ...	−0·21	−0·27	+0·67	+0·84	+0·26
Effect of 0·9 cwt. K_2O ...	+2·22	+0·78	+2·31	+2·27	+1·90
Fosters	14·23	14·76	13·37	14·70	14·27
Effect of 12 tons dung ...	+2·56	+0·96	+2·72	+2·66	+2·23
Effect of 0·5 cwt. N ...	+0·02	+0·72	−0·50	+1·04	+0·33
Effect of 0·9 cwt. P_2O_5 ...	−0·42	−0·06	+0·86	+0·34	+0·19
Effect of 0·9 cwt. K_2O ...	+1·16	+0·70	+0·48	+0·04	+0·59
Third test crop:					
Barley, grain, cwt./acre					
Highfield	31·5	33·2	35·9	36·8	34·3
Effect of 0·2 cwt. N * ...	−2·6	−1·4	+1·0	−5·7	−2·1
Fosters	36·7	38·8	40·3	39·8	38·9
Effect of 0·2 cwt. N ...	+0·3	−0·9	−2·5	−0·2	−0·8

Note: The fertilizer effects are the increases of the double dose of nutrients above the single dose; i.e., the effect of 0·5 cwt. N to potatoes is 1·0 cwt. N–0·5 cwt. N.

* No single dose of nitrogen in this case.

lesser extent on Fosters. The wilt was caused by a fungus, possibly either a *Fusarium* or *Vertillicium* species, and the disease is being investigated in the Plant Pathology Department. Only the last cut of the third-year lucerne on Highfield was estimated to be seriously reduced this year. When the lucerne is ploughed up for wheat the plant is never completely killed, and the wheat always contains a number of lucerne plants. Starting in 1956, these volunteer plants have been killed in spring by spraying with a hormone weed-killer. This may help in reducing the carry over of the wilt infection from one lucerne crop to the next.

The yields of the herbage crops are given in Table 2.

Compared with the average of previous years, the output of dry matter was distinctly low for all the grazed plots in 1956, Highfield being rather more productive than Fosters. The small amount of extra nitrogen, given as 1 cwt. of "Nitro-Chalk", increased the dry-matter production of these plots by an average of 2 cwt. per acre. The season was favourable for cut grass on both fields, and yields well above average were obtained; in addition there was a response of 16 cwt. dry matter per acre for the extra dressing of 1 cwt. of "Nitro-Chalk" given for every cut. In spite of the fungus disease pre-

TABLE 2

Rothamsted ley–arable experiment: Highfield and Fosters
Yield of treatment crops

(Dry matter, cwt./acre)

Year of leys	Old grass Hay	Old grass Grazing	Reseeded grass Hay	Reseeded grass Grazing	3-year ley grazing	Cut grass	Cut lucerne	1-year ley hay
				Highfield				
First ...	41·7	25·3 *	61·5	22·9 *	20·3	59·4	46·2	56·6
Second ...	—	26·9	—	26·2	27·2	73·8	88·0	—
Third ...	—	31·6	—	33·0	30·2	75·7	96·6	—
				Fosters				
First ...	—	—	35·4	18·9 *	16·8	43·1	33·5	46·6
Second ...	—	—	—	22·9	24·0	63·7	90·1	—
Third ...	—	—	—	17·8	22·7	70·6	105·4	—

* Aftermath grazing.

viously mentioned, lucerne in its second and third years produced more dry matter than any other herbage crop.

ANNUAL AND SHORT-PERIOD EXPERIMENTS

These experiments fall into two classes, depending on whether the main interest is in plant nutrition or plant disease. Many of them are carried out by, or on behalf of, the scientific departments who undertake the necessary sampling and observations.

Fertilizer experiments

(1) Spring wheat, Little Hoos. A repetition on a fresh site of the experiment started in 1955 testing " Nitro-Chalk " applied at three times : in the seedbed, as an early top-dressing and as a late top-dressing. All combinations of these three times are being tested, and the nitrogen is given at three rates of application 2, 4 and 6 cwt. " Nitro-Chalk " per acre.

(2) Spring wheat, Little Hoos. A comparison of eight varieties of spring wheat each tested at two levels of nitrogen : 2 and 4 cwt. of " Nitro-Chalk " per acre applied in the seedbed.

(3) Barley, Little Hoos. The same design as experiment (1) above using $1\frac{1}{2}$, 3, $4\frac{1}{2}$ cwt. " Nitro-Chalk " on Herta barley.

(4) Spring oats, Pastures Field. As experiment (2) above with levels of nitrogen 0·36 and 0·72 cwt. N per acre.

(5) Beans, Great Harpenden II. A comparison of autumn-sown and spring-sown beans, including a test of three levels of phosphate and three levels of potash in all combinations. Spraying against aphis was also tested.

(6) Potatoes, Great Field II. A test of four levels of dung, 0, 5, 10, 20 tons per acre, with all combinations of 0·9 cwt. N as sulphate of ammonia, 0·75 cwt. P_2O_5 as superphosphate, 1·5 cwt. K_2O as muriate of potash. Residual effects will be measured in barley in 1957.

(7) Sugar beet, Great Field II. Four levels of dung, 0, 5, 10, 20 tons, together with all combinations of 0·9 cwt. N as sulphate of ammonia, 0·75 cwt. P_2O_5 as superphosphate, 1·5

cwt. K_2O as muriate of potash, 5 cwt. agricultural salt. Residual effects will be measured in barley in 1957.

(8) Lucerne, Great Harpenden II, second year. Three levels of potash, 1, 2, 3 cwt. K_2O per acre, given either in a single application in 1955 or in three equal annual doses in the years 1955–57.

(9) Ryegrass, Long Hoos I. Comparison of forms of nitrogen fertilizer: formalized casein, casein, urea, calcium nitrate, ammonium sulphate. N applied at 0·75 and 1·5 cwt. per acre. Casein products applied in single dressings, others in divided dressings before each of three cuts.

Placement experiments (F. V. Widdowson, Chemistry Department)

(1) Potatoes, West Barnfield I. Sulphate of ammonia 0, 0·5, 1·0 cwt. N; sulphate of potash 0, 0·75, 1·5 cwt. K_2O in all combinations: taken factorially with both constituents broadcast before planting, both constituents drilled in a side band at planting time, one constituent drilled and the other broadcast.

(2) Kale, West Barnfield I. Superphosphate 3 cwt./acre and muriate of potash 2 cwt. per acre in all combinations, broadcast on seedbed and harrowed in or drilled in band 2 inches to the side of the seed. A test of NPK broadcast or drilled is included.

Experiments on soil structure (W. W. Emerson, Physics Department)

(1) Ploughed up leys, Fosters Field. Effect of various five-year leys of pure species of grass and legumes measured in red beet and carrots (first test crops); wheat (second test crop); barley (third test crop).

(2) Ryegrass and cocksfoot leys, Long Hoos I. Second preparatory year of leys.

Experiment on wild oats (J. M. Thurston, Botany Department)

(1) Survival of wild oats under leys, Great Knott I, second year. Certain plots put down to ley in oat-infested land in spring 1955 have been ploughed up in autumn 1956 for examination.

Experiments on beans (J. R. Moffatt, The Farm)

(1) Spring beans, Great Field I. Control of weeds by cultivations and DNBP spray.

(2) Spring beans, Great Field I. Effect of hormone sprays on setting of flowers.

Plant pathology experiments

(1) Wheat, eyespot rotation experiment, Long Hoos II and III, third year (M. D. Glynne, Plant Pathology Department). Two varieties, two seed rates, two levels of nitrogenous manuring, sulphuric acid spray in early spring. All the above treatments are tested factorially on winter wheat in the final year after four different crop sequences. Detailed observations on eyespot (*Cercosporella herpotrichoides*) are made.

(2) Wheat, Long Hoos VII, third year (D. B. Long, Entomology Department). Effect of plant density on incidence of wheat bulb fly (*Leptohylemyia coarctata* Fall.). Testing year under a uniformly treated crop of wheat, after four different degrees of ground cover in 1954 and 1955.
(3) Wheat, Pennell's Piece (R. Bardner, Insecticides Department). Test of four insecticidal treatments against wheat bulb fly.
(4) Wheat and winter oats, Highfield I (G. A. Salt, Plant Pathology Department). Plots of wheat and winter oats singly and in mixture in preparation for an experiment on spring wheat in 1957 studying weed control in relation to the incidence of take-all (*Ophiobolus graminis*).
(5) Spring beans, Great Knott I (M. J. Way, Insecticides Department). Testing four dates of spring sowing, February, March, April, May; with spraying against aphids, in mid-June, in early July and on both occasions.
(6) Potatoes, Great Knott III (G. A. Salt, Plant Pathology Department). Test of four fungicides applied by three methods against skin spot (*Oospora pustulans*).
(7) Potatoes, Great Knott III (J. M. Hirst, Plant Pathology Department). Effect of copper fungicide and burning off haulm with sulphuric acid on late blight (*Phytophthora infestans*).
(8) Potatoes, Great Knott III (L. Broadbent, Plant Pathology Department). Effect of spraying against aphids with DDT insecticides four times or six times, at high or low volume on the spread of leaf roll and virus Y.

Fertilizer experiments, Woburn

(1) Spring wheat, Stackyard C. A repetition of the nitrogen experiment of 1955. " Nitro-Chalk " at three times of application, in the seedbed, as an early top-dressing and as a late top-dressing. All combinations of these three times were tested at 2, 4 and 6 cwt. " Nitro-Chalk " per acre.
(2) Barley, Stackyard C. As experiment (1) above.
(3) Spring beans, Broadmead I. Three levels of phosphate and three of potash in all combinations.
(4) Potatoes, Butt Close. A repetition of the Rothamsted experiment testing four levels of dung with each of the three nutrients NPK in all combinations. Residues will be measured in barley in 1957.
(5) Sugar beet, Butt Close. A repetition of the Rothamsted experiment testing four levels of dung with each of the four nutrients NPK, salt in all combinations. Residues will be measured in barley in 1957.

Plant pathology experiments, Woburn

(1) Winter wheat, Road Piece, third year (G. A. Salt, Plant Pathology Department). Two varieties, two seed rates, two levels of " Nitro-Chalk " applied on four occasions : all early March, all mid-April, all end May, half in March and half in May. Observations on take-all (*Ophiobolus graminis*) were made.

Farmyard manure for sugar beet or potatoes

A new series of experiments was started in 1956 on both farms to compare the effect of dung on sugar beet and potatoes, two crops that often compete for the limited amount of dung available on arable farms. The dung, taken from the same yard, was used at several rates per acre in the presence and also in the absence of the three standard fertilizers; thus, in addition to providing a response curve for farmyard manure on both crops, the experiments were designed to give information on the interaction of dung with the inorganic nutrients. In the sugar-beet series agricultural salt was also tested. It is proposed to follow each experiment by at least one year under spring-sown cereals to measure the residual effects of the manures applied to the roots.

At Rothamsted the sugar beet and potatoes were grown side by side in Great Field II on land still showing some residual fertility after many years in grass. Field observations on the growing crops showed that with potatoes by far the most active fertilizer was superphosphate, which lightened the colour of the foliage and gave marked increases in vegetative growth. Dung was also effective up to 10 tons per acre, but the further increase in growth produced by the highest dose of 20 tons was small. In the sugar-beet plots superphosphate also produced a striking improvement, which was particularly marked in the early stages, though it persisted far into the season. The seedlings on the phosphate-treated plots made a much quicker start and were about twice the size of the others. In the early stages of growth even the heaviest dressing of dung, 20 tons per acre, although visibly beneficial was not nearly so effective as superphosphate. This spectacular result from superphosphate for sugar beet and potatoes is quite unusual at Rothamsted. Potash had no noticeable effect on the vegetative growth of the potatoes, but the final yield was increased except in presence of 20 tons of dung.

At Woburn neither superphosphate nor muriate of potash had any visible effect on potatoes. The main benefit came from sulphate of ammonia, both in growth and colour, and there was a steady improvement with each level of farmyard manure at the rate of approximately 1 ton of potatoes for 5 tons dung.

Alternate Wheat and Fallow, Hoosfield

In the autumn of 1956 the old " wheat and fallow " plots were reduced to half their former size to provide suitable land for field studies of the wheat bulb fly (*Leptohylemyia coarctata* Fall.), while still preserving the continuity of the classical experiment. The change provides a convenient opportunity to summarize the history and long-period results of the experiment.

The land on which the alternate wheat and fallow plots are situated has been completely without manure since 1851. In 1854 the whole area of 1 acre carried wheat, and in the autumn of that year the land was divided into two ½-acre strips side by side, one being drilled with wheat and the other bare fallowed. The crop of 1855 was preliminary, for the wheat followed a wheat crop and not

bare fallow. From 1856 onwards one strip carried wheat after fallow while its neighbour was being bare fallowed for next year's wheat. The variety of wheat was the same as on the adjoining Broadbalk field to give a comparison between continuous wheat without manure on Plot 3 of Broadbalk with wheat after fallow on Hoosfield. Some evidence that the two fields were of approximately equal natural fertility was obtained in the preliminary year 1855, when wheat after wheat on the Hoosfield site gave almost exactly the same yield as Plot 3 on Broadbalk.

The experiment continued unchanged for 76 years; then in 1932 a modification was made to give a yearly comparison of the effect of a 1-year fallow and a 3-year fallow. The strips were each divided transversely into four quarters: when a strip came into wheat after fallow only three of the four quarters were sown, leaving one quarter to be again fallowed; next year this quarter was once more fallowed with the whole of its strip, making three successive bare fallows in all; this quarter was then drilled with wheat. A different quarter of the cropped strip was selected for fallowing every year, hence after a preliminary period of 2 years each phase of the rotation was represented yearly and the treatments followed an 8-year cycle.

The mean yields are taken over two periods. The first covers seven 10-year periods, 1856–1925, when the Hoosfield yields were comparable with those on Plot 3 on Broadbalk. There then followed an 8-year period in which the fallow cycle on Broadbalk and the cycle incorporating a 3-year fallow on Hoosfield were being established. This was completed in 1932, and it is now possible to present two complete 8-year cycles plus 6 years of the third cycle. The corresponding yields from Broadbalk Plot 3 are given 1 year after bare fallow and 4 years after fallow, the latter figure being the closest available estimate of the yield of continuous wheat.

TABLE 3

Hoosfield wheat after fallow, 1856–1925

(10-year means, cwt./acre)

Years	Grain		Straw	
	Hoosfield wheat after fallow	Broadbalk Plot 3 unmanured	Hoosfield wheat after fallow	Broadbalk Plot 3 unmanured
1856–1865	14·3	9·2	22·1	14·0
1866–1875	7·7	6·8	12·6	10·0
1876–1885	8·0	6·2	11·1	8·4
1886–1895	8·3	6·8	11·2	8·2
1896–1905	8·1	6·8	12·9	9·9
1906–1915	6·5	5·7	10·8	8·4
1916–1925	5·2	4·8	8·5	6·6
Mean	8·3	6·6	12·7	9·4

The figures for the original experiment show that the yields of wheat without manure are always low, whether grown continuously or alternately with bare fallow. Wheat after fallow yielded on the average about 25 per cent more than continuous wheat, but in order to justify the system, the yields would have to be at least twice as much as on the unmanured plot on Broadbalk. This was never

obtained, even in the earliest years, when the fallowing effect was greatest. Cultivation, no matter how thorough or prolonged, is not an effective substitute even for continuous cropping without manure, much less for cropping with fertilizer. It is noteworthy that in the early years the advantage due to fallowing was large, +5·1 cwt. grain per acre in the first 10-year period. After that it dropped rapidly, and was only +0·4 cwt. in the last 10 years. If the benefit from fallowing is due, in part at any rate, to release of nitrogen from soil organic matter it might be expected that the early stages of the process, when the soil was better supplied with crop residues, would be more productive than the latest ones. The produce of the wheat and fallow plots differs from that of Broadbalk in the proportion of grain to straw. The Broadbalk experiment always gave a higher grain : straw ratio than the Hoosfield one, and the difference has become more pronounced with time. In the last 10-year period the grain : straw ratio of Broadbalk was 73 per cent, while on Hoosfield it was only 61 per cent.

TABLE 4

Hoosfield wheat after fallow, 1934–1955

(8-year means, cwt./acre)

Year	Grain				Straw			
	Hoosfield wheat Years of fallow		Broadbalk Plot 3 unmanured Years after fallow		Hoosfield wheat Years of fallow		Broadbalk Plot 3 unmanured Years after fallow	
	3	1	1	4	3	1	1	4
1934–1941 ...	10·6	9·7	14·6	8·6	16·8	14·1	27·1	14·8
1942–1949 ...	12·9	11·6	17·7	9·0	20·9	18·4	27·3	14·0
1950–1955 * ...	9·9	9·2	17·0	9·2	15·4	14·2	30·2	16·4
Mean	11·2	10·2	16·4	8·9	17·9	15·7	28·0	14·9

* 6 years.

Under the revised scheme, begun in 1934, yields rose considerably above the low levels recorded in the later years of the old experiment. Broadbalk yields also rose, and the best reference point obtainable from that field is the yield of Plot 3 when carrying its fourth successive wheat crop. On this basis the wheat after the 1-year fallow yielded on the average only 14 per cent more per acre than the practically continuous wheat. In contrast, the 1-year fallow on Broadbalk Plot 3 raised the yield on the average by +7·5 cwt. or 84 per cent. Here, however, the fallow is young in the sense that only 9 bare fallows have so far been taken on these plots, as compared with the 50 or more on Hoosfield. There is thus no justification for protracted bare fallowing on land already clean. The 3-year continuous bare fallow always gives higher yields than the 1-year fallow, but the difference is only 1 cwt. of grain, or about 10 per cent. Under the revised scheme the grain : straw ratio in the wheat-and-fallow experiment has altered very little, but under the fallowing system on Broadbalk this ratio for the unmanured plot has fallen from 70 to 60 per cent; thus the Hoosfield experiment is now giving a higher proportion of grain to straw than the corresponding plot on Broadbalk.

The wheat-and-fallow experiment has been under observation by the Plant Pathology Department for many years. Eyespot (*Cercosporella herpotrichoides*) occurs on all plots, but is less severe after the 3-year fallow than after the 1-year fallow. Take-all

(*Ophiobolus graminis*) is present in only negligible quantities, for it is controlled by fallowing. A disease called the "white straw disease" caused by the fungus *Gibellina cerealis* has been noted practically every year since it was first found by M. D. Glynne in these plots in 1935. The disease has been recorded from time to time in Italy since 1886, but the wheat-and-fallow experiment is its only known habitat in Britain. It causes severe damage to infected plants, but on the wheat-and-fallow plots so few plants are attacked that the yield is not appreciably affected.

Rothamsted Garden Clover

In 1849 an attempt was made to grow red clover continuously with different manurial treatments on one of the ordinary farm fields. It was only in the first year that a really good crop of clover was obtained, and on 21 occasions the plots were not fit to weigh. When it was clear that red clover would not succeed year after year on farm land, a fresh start was made in 1854 on a very rich soil that had been under garden cultivation for at least two centuries.

The garden clover, as it is always called, was set down on a small plot only 8 feet by 12 feet in the kitchen garden near Rothamsted House. When the grounds round the house were freshly laid out towards the end of the nineteenth century the little plot found itself in one of the new lawns, and being included in the schedule of classical experiments, it was carefully railed off and preserved. There it has remained ever since, tended by hand at sowing and hay-time, but otherwise little visited, and in fact unknown to many of the Rothamsted workers.

In 1955 analysis of the surface soil showed that the plot, which had received no fertilizer for at least 60 years and had all its produce removed, was extremely deficient in potash. Consequently in May 1956 it was divided into two sub-plots to test annual dressings of muriate of potash at the rate of 2 cwt. per acre. Since the experiment will now be continued under this new scheme, it is perhaps appropriate to summarize its past history and performance.

The plot was sown in spring 1854, and no further seedings were made as long as the plants persisted. The first sowing lasted for 6 years and the second for 5 years. In the first 20 years the plot was resown on 5 occasions only, but thereafter either complete resowing, or more frequently patching, was almost a yearly operation. Thus in the last 55 years the plots have been resown 17 times and mended 27 times. Few individual plants survive more than two seasons.

In the early years the plot was divided into three parts to test cumulative dressings of gypsum and of mineral fertilizers. In 1896 a basal dressing of chalk and fertilizer was thoroughly incorporated with the soil to a depth of 18 inches. Since then the plot received no fertilizer till the present test of muriate of potash began in 1956.

The yields of green stuff averaged over 10-year periods since 1854 are given in Table 5 below.

The yields over the first 10-year period were very high indeed, averaging 22 tons green or about 4·9 tons reckoned as hay with 83 per cent moisture. The crop in the first year after sowing, i.e., when

TABLE 5

Rothamsted garden clover, 1854–1956

(10-year means, green weight of produce, tons/acre)

1854–1863	22·37
1864–1873	10·09
1874–1883	11·32
1884–1893	11·44
1894–1903	4·56
1904–1913	6·09
1914–1923	3·48
1924–1933	2·04
1934–1943	2·06
1944–1953	3·02
1954–1956	1·12 *

* 3 years only.

red clover makes its biggest growth, was no less than 39 tons of green stuff as a total of three cuts, or 6·7 tons dry matter per acre. This is probably a reflexion of the fact that the surface soil contained 0·509 per cent N in 1857, and presumably was also well supplied with the other nutrients. Moreover, clover had not been grown there before. The next 10-year period gave on the average only about half the yield of the first, but 10 tons of green stuff would still be regarded as a fair crop by agricultural standards, and this level of production was maintained over 30 years. During this period yields varied considerably from year to year, but there were 4 occasions when really high figures of over 20 tons of green stuff per acre were reached; the last of these occurred in 1889 after 35 years of continuous cropping. After 1893 production showed a marked decline; no more large crops were grown, but there were several complete failures. As late as 1951 a yield of green stuff of 5 tons per acre was recorded. In the last few years the crop has been of the order of 1 ton green stuff/acre, and little more useful yield information could be expected from the original scheme. Although the fact that clover would grow at all under continuous cropping was a matter of great interest, the pronounced deterioration in the later years of Lawes and Gilbert presented a problem. Several measures appear to have been tried: in 1896 mineral fertilizers were thoroughly mixed with the soil to a depth of 18 inches; in the following year the plot was "microbe-seeded" with a water extract of a good garden soil, and in 1898, when *Sclerotinia trifoliorum* was confirmed, the diseased plants were burnt, sclerotia were carefully removed from the surface soil and the plot was disinfected with carbon bisulphide. The same treatment was repeated in the following year. About the same time stem eelworm was found attacking the plants.

The first year's result of the potash dressing applied in spring 1956 is:

TABLE 6

Rothamsted garden clover, 1956

	Dry matter, cwt./acre			Potassium in dry matter per cent	
	1st cut	2nd cut	Total	1st cut	2nd cut
Unmanured	0·4	0·8	1·2	1·0	1·1
2 cwt. muriate of potash	0·4	3·8	4·2	1·1	2·4

The potash was applied only two months before the first cut was taken and affected neither the yield, which in any case was negligible, nor the composition of the produce. The second cut, however, which was taken four months after application, showed some improvement in yield and in potash content. The effect of further yearly potash dressings will be measured.

THE FARMS

J. R. Moffatt

Rothamsted

The weather in 1956 was very unusual. After the reasonably favourable autumn of 1955, the year 1956 started with land work well up to schedule. Spring operations started rather late, but the dry weather enabled all crops to be sown in good time. The dry spell developed into a spring drought which lasted until the end of May, retarding the germination and growth of most crops. Three months of exceptionally bad weather followed. Heavy rain and strong winds did much damage to hay and corn crops, while low temperatures and lack of sun delayed the ripening of the cereal and pulse crops. Both yield and quality of grain suffered, while harvesting costs were high. Some compensation was afforded by the fact that the root crops made good growth during the summer, and improved weather conditions in the autumn enabled these heavy crops to be harvested under good conditions. Land work, which had fallen seriously behind, was again up to schedule by the end of the year.

The Effect of Weather on Crops

Weather during the autumn of 1955 was generally mild and dry, and all the root crops were lifted by early December. Winter wheat was sown under excellent conditions, Broadbalk being drilled on 2 November 1955. The mild weather encouraged the germination of weed seeds, and a second ploughing was given to several areas to kill the seedlings. Weather in January 1956 was very changeable, and little land work was possible. At the end of the month a severe cold spell started and, with the exception of a short thaw about the middle of the month, continued until the end of February. Ground or air frosts occurred on 26 days, and the mean air temperature was 9° F. below the average. The cold spell broke on the last day of February, and the ground thawed out rapidly in March. However, the land was then so wet that no work could be done for several days. The generally dry and sunny weather during March enabled the preparation of seedbeds and the sowing of spring cereals to go ahead rapidly, as the ground worked down easily. However, there were many night frosts which impeded the work, and winds were cold. The preparation of the land for root crops followed, and the planting of main-crop potatoes started in March. April was a cold, dry month, frost being recorded on 18 occasions and rainfall being recorded on only 9 days. The planting of the potato and root crops and the grasses and clovers was completed during the month.

The dry spell continued almost unbroken throughout May, rainfall being recorded on only 8 occasions and totalling 0·63 in. Temperatures were higher than normal, and hours of sunshine were well

above average; May was in fact by far the sunniest month of the year. There were, however, two sharp frosts during the third week of the month, but fortunately little damage was done. Throughout the four spring months February–May the total rainfall was less than 3·5 inches compared with the normal 8 inches. This dry weather retarded the growth of all corn crops and grass. The early-sown sugar beet carried a good even plant, though growth was slow, but the later sown beet and mangolds germinated very slowly and unevenly.

June brought a complete reversal of weather conditions; the rainfall totalled nearly 4 inches, more than in the previous three months together, and spread over 16 days; the mean temperature and hours of sunshine were well below normal. All crops made a spurt of growth, and a second germination took place on all root seeds, lucerne, grasses and clovers. There was also a very rapid germination of weed seeds, and fields which looked perfectly clean at the end of May soon became very weedy. July was another wet and cool month, with little sunshine, and there were several heavy storms. The weather retarded the ripening of cereal crops and caused lodging in considerable areas of barley. Haymaking was also severely affected by the bad weather in these two months, yet most of the hay was of quite fair quality. Potatoes, sugar beet and kale maintained good growth throughout the month.

The weather during August and early September was very bad. It was cool and almost sunless, with heavy rain and gale-force winds. The rainfall in August totalled 5·34 inches, over twice the normal, and was spread over 24 days. Many of the cereal crops became badly lodged, and grain in both lodged crops and in standing corn sprouted in the ear. The crops were very slow to ripen, and harvesting did not begin until early September. In some fields where early lodging occurred weeds grew through the lodged crops and presented many difficulties at time of cutting. Much of the corn was combined when containing about 25 per cent moisture, but on some small experimental areas the moisture content rose to over 30 per cent. Each batch of corn had to remain on the platform drier for much longer than usual, and almost every load of grain needed drying. Potatoes and other root crops continued to make good progress under these conditions, but Late Blight (*Phytophthora infestans*) spread rapidly despite protective sprayings. The weed problem in the root crops became acute under the wet conditions; however, the extra help engaged for the harvest but not used for this work, helped to keep them under control. The conditions suited the grassland, which maintained good growth throughout this bad spell of weather. The bean crop continued to grow in height, but ripened extremely slowly. The latter part of September was mainly dry, with bright spells and temperatures considerably higher than in the early part of the month. The cereal harvest was completed by the end of the first week in October, about three weeks later than usual, but the harvesting of the bean crop was not completed until mid-October, and even then it was barely ripe.

The improvement in the weather lasted through most of October and although there were 17 rainy days the rainfall was well below average. Potato lifting followed the end of the cereal harvest and

went on steadily until it was finished about mid-November. Yields were high, but the tubers were rather dirty, and many of them were split as a result of the excessive rain. The weather also favoured autumn ploughing, but the furrows turned up in a rather wet and solid condition, which made it difficult to prepare seedbeds. However, the drilling of winter cereals started during the third week of October although on Broadbalk field the drilling was delayed until 7 November by strong winds which prevented the sowing of fertilizers.

November was a dry month, and the small amount of rain, which was mostly light and was spread over 16 days, was less than one-third of the normal. There were several sharp frosts towards the end of the month, by which time the arrears of ploughing and other autumn cultivations arising from the protracted harvest had been overtaken. The harvesting of the potatoes was followed immediately by the lifting of the mangolds and sugar beet.

The early part of December was dull but dry, and good progress was made with the beet harvest. Later the weather deteriorated, and during the last week there was sleet and snow. This slowed down the beet harvesting, and conditions steadily worsened, so that the work had to be abandoned for 10 days and was finished early in January 1957.

Field Experiments

The field experiments programme was again very full, but the favourable conditions in autumn and spring enabled it to be carried out. The wet, stormy summer caused severe lodging on many of the cereal plots, especially barley plots, and harvesting was a difficult and protracted operation. However, the combine harvester was able to make a much more satisfactory job of the harvesting than the binder would have done, and losses of grain were small. The only experiment which suffered much from loss of grain was the Deep Cultivation experiment, where the oats shed badly before they could be cut. It was possible to combine the cereal plots at a high moisture content, since the running-out time between the plots allowed the combine to be kept busy without producing too great a bulk of grain for drying. The yields were corrected to a standard moisture content of 15 per cent. A very large proportion of the cereal plots were cut by combine, and it is hoped that by the 1957 harvest all plots, including the Classical plots on Broadbalk and Hoosfield, will be dealt with in this manner.

On Broadbalk field the wild oats were hand-pulled on two occasions, and the field appeared to be clear. However, when threshing took place there were a few wild oat seeds in the wheat. On Hoosfield, where wild oats have been extremely bad for the past few years, all the plots were hand-pulled once, and the worst of them twice. The drilling on Hoosfield was delayed until 3 April to get an initial germination of wild oat seeds which were destroyed in subsequent cultivations. This weed was also hand-pulled from the Exhaustion Land.

The beans on the experimental plots ripened very slowly, and to get the ground cleared while weather and soil conditions were good

they were harvested before they were really fit, thus having a very high moisture content. The yields were corrected to a standard moisture content. The combine dealt with these conditions very well.

On some of the potato experiments a larger amount of soil than usual adhered to the tubers at lifting time, but a dirt tare was taken from a sample bag from each plot.

Towards the end of the sugar-beet harvest the soil conditions were bad, and the tops and loose leaves which had to be weighed became wet and muddy. Throughout this operation the soil stuck firmly to the roots, which had to be scraped clean individually.

The mangolds on Barnfield had an unhappy year. The plots receiving sulphate of ammonia were given a heavy dressing of calcium carbonate in spring to correct the acidity, and this involved going over the ground several times with the tractor and drill. The ground was then worked to remove wheel marks before drilling. These operations took place in late March and early April, and resulted in a loss of moisture and a rather poorer tilth. Unfortunately two months of dry weather followed, so that there was insufficient moisture for a reasonable germination, and the plant was very thin and gappy on these and certain other plots. When rain came early in June the balance of the seeds germinated, but weed seeds germinated more rapidly, and singling would have been impossible. It was therefore decided to fallow all plots except those carrying a reasonable proportion of early germinated plants. In effect, this meant leaving only the two dunged strips and the plots receiving nitrate of soda.

The mangolds on these plots made good growth throughout the summer, and the roots were bigger than for several years.

Cropping and Rotations

Of the total of 442 acres farmed 74 were under permanent grass, 129 under short-term leys and clovers and 239 under arable crops. The latter consisted of 95 acres of wheat, 26 acres of barley, 22 acres of oats, 29 acres of beans, 28 acres of potatoes and 11 acres of kale, mangolds and sugar beet.

Because of the constant necessity of providing sites for cereal experiments on land free of weed and disease, the revision of the cropping programme mentioned last year has been continued. The acreage of barley and wheat was reduced by a further 30 acres and that under beans very nearly doubled. The oat acreage has been increased more than twofold, while 8 acres of land maintained in a state of low phosphate and potash fertility were fallowed. One field of 15 acres which had borne its fair share of cereal crops was undersown with a normal seeds mixture, and another of 12 acres was sown down in the spring to cocksfoot and lucerne drilled in alternate rows. It is hoped that this latter type of ley, which allows of some cultivation in the early spring and after each cut, will help to solve the problem of resting a field from the normal arable crops while also ridding it of wild oats and other arable weeds. Should it prove successful, the acreage will be extended in future years.

Control of Weeds, Pests and Diseases

The peculiar weather conditions of 1956 brought out special problems on the incidence and control of weeds, pests and diseases.

Weeds

Some areas of land infested with couch grass (*Agropyrum repens*) were sprayed with TCA at 40 lb./acre split into two doses, and on the whole satisfactory results were obtained. When the application was made in the spring after the hard February frosts, some damage occurred to the following crops of potatoes and lucerne. This is probably explained by the fact that the material had not been washed down owing to the dry spring, since in past years no such damage has occurred.

There was an unusually bad infestation of cleavers (*Galium aparine*), chickweed (*Stellaria media*) and of redshank (*Poligonum persicaria*) in many of the fields sown to cereals. As these weeds are resistant to hormone weed-killers, a much larger area than usual had to be sprayed with DNOC. This was applied at high volume (90 gal./acre) when the crop was in the three-leaf stage, a much earlier stage than usual for spraying, and the weeds were still seedlings. Excellent results were obtained, but unfortunately at a later date a crop of creeping thistle (*Circium arvense*) appeared which, in some cases, necessitated spraying with MCPA.

DNBP (ammonium salt) was used to control an extremely heavy infestation of redshank (*Poligonum persicaria*) in a field of spring beans. This material is not recommended for use on spring-sown beans, and the striking success achieved was attributed to the fact that, owing to the drought, the bean plants were in a short, hard stage of growth at the time of spraying. After the heavy rain early in June a second heavy infestation of the same weed occurred again; this could only be dealt with by the routine inter-row cultivations, which, of course, did not destroy the weeds in the rows.

A small area of kale was sprayed with "Dipakal" to see its effect on the weeds and the crop. However, weather conditions were very unsuitable and the results inconclusive.

Weeds in potatoes and other root crops were kept under control easily in the early part of the season, but the heavy rain during the summer encouraged rapid germination and growth of weeds, which under the prevailing conditions were difficult to control, so that much hand hoeing was required.

Pests

On an old arable field which had been dunged and planted with potatoes it was observed that nearly every "seed" tuber was being attacked by wireworms soon after planting. As a precautionary measure the field was sprayed with aldrin, and although it is impossible to know how the attack might have developed had the spraying not been done, the result was a crop quite free from wireworm damage.

Three separate areas of kale were sown during the spring drought, and with the help of a γ-BHC seed dressing, and spraying with

miscible DDT against flea beetles, a satisfactory plant was obtained in all areas.

Both spring beans and lucerne were fairly severely attacked by the pea and bean weevil (*Sitona lineata*) and had to be sprayed with miscible DDT. The attack on beans was particularly persistent even to a fairly forward stage of growth, and one area had to be sprayed as late as early June.

All spring beans were sprayed with "Metasystox" against a possible infestation of black fly (*Aphis fabae*). Weather conditions were against a bad outbreak, and fortunately none occurred.

In a large patch in a field sown to a lucerne–cocksfoot ley, lucerne plants several inches tall were seen to be dying off. Investigation showed that the damage was caused by millepedes (*Blaniulus guttulatus*), against which no treatment is effective.

Diseases

In the cereal crops one area was badly attacked by take-all (*Ophiobolus graminis*), while eyespot (*Cercosporella herpotrichoides*) occurred in varying degrees of intensity over much of the farm. With the longer rotation now being used it is hoped that the intensity of eyespot will diminish. Much of the lodging of the corn this year was, in part at least, due to the elements. Loose smut (*Ustilago nuda*) was very prevalent in the Herta barley, while the spring oats were badly attacked by the frit fly (*Oscinella frit*) in spring and when in ear.

Despite preventive sprayings of the potato crops against late blight (*Phytophthora infestans*), the disease spread rapidly in late August and September, but fortunately few of the tubers were damaged.

Crops

Wheat

The favourable autumn enabled the planned acreage of winter wheat to be sown. Of the 70 acres, 26 were sown to Heine's VII, 8 to Banco and 19 to Cappelle, with smaller areas of Yeoman and Squarehead's Master 13/4. All the varieties withstood the hard weather in February very satisfactorily, and no patching was needed. Twenty-six acres of Koga II, our standard spring variety, were sown, and one piece, with a yield of 43 cwt./acre, out-yielded both Heine's VII (28–35 cwt./acre) and Banco (26–32 cwt./acre). Most of the wheats stood well considering the season; Koga II was outstandingly good. Heine's VII leaned badly but did not go flat, but the Yeoman and the Squarehead's Master in Broadbalk were badly laid. A lot of wheat sprouted in the ear, and this, and the combining at a high moisture content, greatly reduced the germination of the crops grown for seed. The few plots which were cut by binder sprouted badly in the shocks.

Much of the grain is rather small and thin, and badly discoloured, and will need careful cleaning before sale.

Barley

The acreage under this crop was reduced to 35. Proctor is now the main variety grown, though there was a small acreage under

Herta. Plumage Archer is now grown only on Hoosfield and in certain other small experimental areas. In general, yields, averaging 25–28 cwt. acre, were disappointing, though mean yields of up to 40 cwt. acre were obtained from some experiments. Several areas were lodged, but the combine-harvesters were able to deal with lodged crops very satisfactorily. Some sprouting in the ear took place, and though it was not so bad as with wheat, the quality of the grain is poor. The barley crop came into ear this year much earlier than usual, probably as a result of the dry spring.

Oats

There was a considerable increase in the acreage under this crop, and 15 acres were undersown. Sun II, which has consistently outyielded its sister variety Blenda, is now our standard variety, though in a variety trial this year it took fourth place. There was a bad attack of frit fly, both in the early stage of growth and when the crop was in ear. The dry spring also played its part in reducing the yield, which averaged only 20 cwt. acre. There was a lot of sprouting in the ear before cutting, and on the small area cut by binder the sprouting in the shocks was extremely bad. The grain is therefore of poor quality.

Beans

Only a small acreage of winter beans was sown, but that of spring beans was increased to 25 acres. The crop made a slow start, but the wet weather during the summer seemed to suit the crop, which yielded an average of 25 cwt. acre. The crop grew very tall and remained green much longer than usual. Although cutting was delayed until well into October, there were still some green leaves. The combine-harvester dealt well with the crop, although the moisture content was well over 30 per cent; but drying took a long time.

A preventive spraying against black fly was given and no attack developed. Yellow leafroll of beans was seen in the crop, and in some areas up to 4 per cent of the crop was affected. It is not known what effect this disease has on the yield of the crop.

The first of a series of experiments comparing the yields and susceptibility to damage and disease of winter and spring beans was carried out at Rothamsted and Woburn. The winter beans were damaged somewhat by the hard frosts, but very few plants were killed.

Potatoes

Twenty-eight acres were devoted to this crop—about the maximum that can be harvested satisfactorily. After a slow start in the dry spring the crop made rapid growth throughout the summer. The main variety grown was Majestic, which yielded 12–14 tons acre. The King Edwards yielded 10 tons acre (approximately) and were sprayed on three occasions against late blight. Ulster Supreme was grown for the first time; it yielded excellently (14 tons acre), and cooks well. However, it appeared very susceptible to late blight and does not seem to keep well. A further acreage of this variety will be grown in 1957. The tubers of all varieties were of good size

and shape, and free from damage, except for some split tubers in the Majestics.

On all areas the haulm was burnt off by sulphuric acid or sodium arsenite some time before lifting. On some areas where there was a lot of chickweed the sodium arsenite killed off the potato haulm and bleached the leaves of the chickweed. The plants did not appear to be killed, and at lifting time the weed was almost as much trouble as if no haulm killing had been done.

Although weather conditions at lifting time were favourable, in many places the soil was wet and stuck badly to the tubers.

Kale

Both marrow-stem and thousand-head varieties were grown. Growth in the early spring was very slow, but flea beetle damage was prevented by a γ-BHC seed treatment and by spraying with miscible DDT. Throughout the summer the crop made very rapid growth and soon smothered the weeds. The yield is estimated at about 30 tons/acre.

Sugar beet and mangolds

Owing to the heavy labour demands of these crops their acreage was kept to a minimum, and they were grown only on experimental areas. Reference has already been made to the mangolds in Barnfield. The early-sown sugar beet carried quite an even plant, but in the later-sown areas the plant was uneven owing to irregular germination. Good growth was maintained during the summer. Yields were well above average (up to 20 tons/acre), and the sugar content for most of the crop averaged about 17 per cent. There was, however, a big drop in the sugar content of the last two truckloads, which were lifted in the latter half of December and which were sent to other factories. These had a sugar content of 15 per cent.

Grassland

Some of the grass fields were given an early top dressing of nitrogen to produce early growth, and many of the other fields were given a complete fertilizer dressing in the spring. However, the cold, dry weather throughout March and April severely retarded growth. There was no spring flush, and the cattle were not turned out from the yards until 8 May. There was just sufficient grass to keep the stock going throughout the dry May, and the heavy rain early in June came just in time to avoid the necessity of having to open one of the hay fields for grazing. During the rest of the year grass was abundant.

At the end of May the hay crops looked very light, but rapid growth took place after the rain in June. Cutting was delayed by the bad weather, and much of the crop became rather stemmy. Most of it was cut in July, but bad weather during the making caused severe leaching and bleaching on some areas. No crop was lost, and considering the weather conditions, the hay was saved in surprisingly good condition.

Livestock

Cattle

At the beginning of the winter there was a large stock of hay and straw and also grain seconds from the 1954 and 1955 harvests. Fifty-two crossbred Hereford cattle, purchased in the late autumn, were put into a temporary open yard adjoining the straw stacks to utilize these materials and to make dung. Other cattle were yarded in the late autumn, and all came through the winter well. Because of the shortage of keep they were not turned out until early May, but they subsequently did well on the abundant grass. They have been sold regularly since May, off the grass, and altogether 76 have been sold. The few remaining at the end of the year have again been yarded, but should be cleared within a few weeks.

A preliminary tuberculin test was carried out in late autumn, and as soon as all the reactors are disposed of a bunch of attested cattle will be purchased to graze down the rough grass and the lucerne–cocksfoot sward. It is hoped to qualify for the Attested Herds Scheme during 1957.

Sheep

The Scotch Half-bred ewe flock was mated to Suffolk rams, and most of the lambs have been retained for grazing experimental field plots at Rothamsted and Woburn in 1957. From the 73 ewes put to the tup 122 lambs were reared, of which 38 have been sold fat.

During the year there were several cases of worrying by dogs, some sheep being killed and many others being so badly mauled that they had to be slaughtered. Careful consideration will have to be given to the question whether the keeping of sheep is justified in an area where dogs abound.

Implements

Because of the restriction on capital expenditure the purchase of new implements and equipment was kept as low as possible. One of the old vaporizing-oil tractors was exchanged for a diesel-engined tractor of the type on which we have standardized, and a second Land-Rover with metal top was bought. A few small pieces of equipment were also purchased, including a fitter's hearth and a set of mounted zig-zag harrows.

Grain-drying and Storage Plant

The 50-hole platform drier was installed in 1952 to deal with a 6-ft. combine-harvester. Now that the combine strength has been increased to two 10-ft. machines it has not sufficient capacity to deal with their output in a wet season. Various other types of drier have been examined, and the advice of many experts has been sought.

In 1955 it was decided to use radially ventilated bins for drying and square galvanized metal bins for storage. It was hoped that all the preparatory work and the erection could be done by the regular farm staff during the summer of 1956 and the plant would

be ready for the 1956 harvest. However, pressure of other work prevented this being done, and work did not commence until 1 August 1956. But since no harvest work could be started that month, good progress was made, and the storage bins were erected in time to hold the corn dried on the platform drier. Eight storage bins, each holding about 20 tons of wheat, have been put up, followed by 4 circular expanded-metal drying bins, each holding 11 tons. It is hoped that the moisture extraction rate will be in the order of 1½–2 per cent/day. It is proposed to use the fan and heater of the platform drier, which are capable of ventilating two bins at a time. The top conveyor is of the endless-belt type, while a jog-trough conveyor is being used for the emptying of the bins. No pre-cleaning will be done at the start, as it is hoped that this may be unnecessary. The existing aspirator and sieve type of cleaner will be used to clean the grain before bagging off for sale. A plant of this size should be able to handle comfortably the output of our two 10-ft. combine-harvesters, one of which will spend much of its time cutting the produce of experimental plots.

The existing platform drier will be removed from its present position and re-erected adjoining the new plant so that the one fan and heater can be used for either the drying silos or the platform drier. The latter drier will be very useful in dealing with small quantities of grain which cannot be so conveniently handled by the ventilated bins.

Estate Work

Some progress was made in the early months of 1956 with the clearing of the derelict apple orchard in Whittlocks field which was purchased in 1955. The work was very tedious because of the miles of supporting wire to which the cordon trees are fastened. A grant under the Marginal Production Scheme has been secured for this work, and it is hoped to make better progress in the early months of 1957.

A large part of Knott Wood, which was replanted in 1940, was cleared of coppice and weeds during the winter of 1955–56, and probably no further treatment will be needed until a first thinning takes place about five years hence.

An inspection of all our woods was made by the Forestry Commission during the year. Their recommendations involve the clearing and replanting of some areas, patching others and a considerable amount of thinning. This work will be undertaken, but must be spread over several years, since only a small amount of time each winter can be spent on the woodlands.

Purchase of Land

During the year three areas of land adjoining our southern boundary were purchased, rounding off our property on this side. The two pieces under grass, totalling 22 acres, have been rented by us for many years but were potential building sites. One piece was purchased as building land, but planning permission having been refused for the larger piece, this, together with Geescroft wilderness (3 acres), was bought at agricultural values.

Staff

B. Weston retired from the post of Field Superintendent on 31 December 1956. J. M. Bidgood has been appointed to the vacant post, which in future will be known as that of Chief Recorder.

Woburn

The work of the Woburn Farm is directed and managed by the staff of the Rothamsted Farm. The field experiments are planned by the Field Plots Committee, while the day-to-day planning is done by the bailiff at Woburn.

The effects on crops of the appalling weather of 1956 were similar to, though perhaps not so severe as, those at Rothamsted. For cereals it was a disappointing year, but it suited potatoes and sugar beet. In addition, serious damage was caused by birds to some crops.

The Effect of Weather on Crops

The mild autumn of 1955 enabled the winter ploughing, which included a piece of grassland on the heavy soil, to be completed before the end of the year.

In January 1956 the weather was very changeable, and a severe spell of frost lasted throughout most of February. After the land had dried out in March a long spell of fine weather enabled the spring corn and beans to be sown reasonably early and under good conditions. The continuation of the dry spell throughout April facilitated the preparation of the ground for, and the planting of, the potatoes and sugar beet. The dry spell continued throughout most of May, and it was accompanied by cold winds. Germination of root crops was delayed and growth was retarded on all crops. There was a very sharp frost in mid-May which caused considerable damage to several areas of early potatoes, and early sown maincrops were also damaged. The leaves of the spring beans also suffered damage. The total rainfall for the four months February–May was only just over 3 inches, less than half the normal.

Throughout June, July and August the weather was very wet. Early in June all crops made a spurt of growth, and a second germination occurred of all root crops and small seeds. Good growth was maintained throughout July, especially by potatoes and sugar beet. The cereal crops came into ear earlier than usual and when the straw was rather short. Despite this, ripening started later than usual and was a very slow process.

The heaviest rainfall of the year was experienced in August when 4·19 inches was spread over 22 days. The start of harvesting was consequently delayed. Only one field of barley was badly laid, and this had to be cut with a mower.

All the barley crops ripened very unevenly, and the grain was badly discoloured and of very uneven quality. Spring wheat was very slow to ripen, and quite a lot of sprouting took place in the ears of the standing crops. The spring beans looked as though they would never ripen and were not cut until the third week of October.

Late blight began to spread rapidly under the damp conditions of early September, so the haulm on all areas was burnt off with sodium arsenite. Fortunately the weather improved in the latter half of the month, and the harvesting of the cereals was completed before the end of the month.

The improved weather conditions lasted throughout October and November, and this greatly helped the harvesting of the heavy crops of potatoes and sugar beet. Good progress was also made with the autumn ploughing, while the small acreage of winter corn was sown under good conditions. There were two very sharp frosts in the middle of November, which did some damage to sugar beet which were pulled and ready for topping.

Cropping

Of the 127 acres farmed 20 acres were under wheat, 24 under barley, 27 under potatoes and 8 under beans. There were smaller acreages of sugar beet, kale and lucerne. Seven acres of ley were ploughed and sown to spring wheat, while 4 acres were undersown with a ley mixture.

Beans were introduced into the rotation this year, since too frequent cropping with cereals and potatoes has led to rather frequent attacks of eyespot and take-all, while many of the fields are affected to a moderate extent with potato-root eelworm. Oats will probably be grown again in 1957 as an alternative to wheat or barley.

Field Experiments

The classical wheat and barley plots were all fallowed in 1956 in order to eliminate the twitch *Holcus mollis* from the wheat ground and *Agrostis gigantea* from the barley ground. Half of each of the wheat and barley plots was sprayed with TCA at 40 lb./acre in the winter of 1955–56, and as this appeared very successful in reducing the amount of twitch, the other half of each plot was sprayed at the same rate during the late summer of 1956. Both wheat and barley areas will be fallowed during 1957 to try to eliminate the twitch, and supplementary applications of carbonate of lime will be applied if necessary to bring all the plots to the same pH status.

Several of the long-term experiments were modified. The six-course rotation testing several levels of fertilizers over a long series of seasons had the level of nitrogen doubled, and this had a very marked effect on the yields of most crops in the rotation. In the market-garden experiment testing the effect of heavy dressings of bulky organic manures, the very vulnerable crop of spring cabbage was replaced by early potatoes. In the ley and arable rotation experiment, because of the presence of potato-root eelworm on some plots, the potato test crop was replaced by sugar beet, while carrots took the place of sugar beet in the arable rotation. Modifications were also made to the rates of manuring.

The number of short-term experiments increased considerably, as harvesting is simplified by being able to use one of the self-propelled combine-harvesters from Rothamsted. Three large cereal experiments were handled in this way. For the first time there

was an experiment on spring beans, and there was also a big increase in the number of potato and sugar-beet plots.

The cereal crops from the long-term experiments were all cut by binder and were carted in good condition. They were threshed during periods of bad weather, and the operation was completed before the end of September.

The first-year lucerne on the ley–arable experiment was severely attacked by the pea and bean weevil (*Sitona lineata*) at an early stage, and the plots had to be dusted and sprayed with DDT.

The carrots in this same experiment grew very slowly at the start. Rapid growth took place later, but when they were lifted the roots were badly fanged, and about 90 per cent of them were badly split. They can only be used as stockfeed.

The seeds undersown in the experiments all took well, as did those after early potatoes in the green manuring experiment. The leys in the ley–arable experiment were very productive, and extra sheep had to be used to keep on top of the growth.

General Notes on Crops

Wheat and barley

Owing to the risk of damage by birds during the winter, very little winter corn was sown. This survived the winter well. The spring corn was all sown in good time, but early growth was severely checked by the cold, dry spring. The dressings of nitrogen to the non-experimental crops were delayed by pressure of experimental operations and did not go on until towards the end of April. It is hoped to overcome this difficulty in future by combine-drilling the nitrogen with the seed. The crops looked a little patchy in May, probably because the nitrogen had not had time to produce any effect. Most of the crops were sprayed with a hormone weed-killer. All the crops, especially the barleys, came into ear much earlier than usual and while the straw was still short. Had it not been for this, lodging might have been more serious. They ripened very slowly and unevenly in the wet, cool summer, and the quality of the grain is poor. Both varieties of spring wheat, Koga II and Peko, stood well despite the adverse conditions. Of the two barley varieties Herta stood better than did the Proctor, one piece of which was very badly laid. No threshing has yet been done, but the yields are not expected to be very high.

Beans

A small area of winter beans was sown, but this was completely destroyed by birds during the winter. The spring beans grew well, and there was no infestation with black fly (*Aphis fabae*). The crop grew very tall and was very slow to ripen. Yields were quite satisfactory from the heavy soil, and it remains to be seen what the crop does on the light, sandy soils.

Potatoes

This crop made excellent growth throughout the summer and was kept clean without any hand hoeing. Majestics were grown on all experimental areas, but once-grown King Edwards from stock

seed grown the previous year at Rothamsted and Woburn were used on non-experimental areas. These plants looked quite healthy throughout the season. The Majestics were of good size and shape; wireworm damage and scab was negligible. The individual tubers of the King Edwards were rather small, though relatively free from blemish, and even after sorting, the appearance of the sample was disappointing. Yields were also below expectations. Three precautionary sprayings against late blight (*Phytophthora infestans*) were given to the King Edwards and two to the Majestics, and though the disease spread rapidly in the early September, only a little disease reached the tubers.

On one small area growth was affected by an application of TCA at 20 lb./acre just under 4 weeks before planting.

Kale and sugar beet

The very small acreage of kale grown for the pigs grew well after a slow start, and gave an extremely heavy yield.

As in 1955, the germination of the sugar-beet seed was very slow and uneven. When the early germinated plants were fit for singling others were about an inch high, while some clusters had not germinated at all. In order to keep down weeds these small plants had to be hoed out, and so the final plant was far from perfect. A large number of eggs of the leaf miner (*Pegomyia betae*) were seen on the leaves, but damage was prevented by spraying with parathion as soon as the larvae hatched out. The crop made good growth during the summer and developed large tops, but there were very few bolters. Yields were well above normal, and the sugar content averaged about 18 per cent, except for one load which contained beet which had been caught by frost, and the sugar then dropped to 15 per cent.

Market-garden crops

The spring cabbage were completely destroyed by frost and birds, and were replaced by early potatoes. These suffered badly from the mid-May frost, and lifting was delayed by bad weather until 24 July. They yielded over 8 tons/acre.

The germination of the red beet was very irregular, but it was apparent that there was a much more regular and vigorous plant on the plots which had received organic manures.

The hard weather in February delayed the start of lifting the leeks until March, and the crop was lighter than usual. Those planted out in early August looked very yellow and sick for a time after planting out, but subsequently recovered. The crop was damaged by hares taking the flag when the snow was on the ground at Christmas.

Grassland

The grass made very little growth in the early part of the season owing to the cold, dry spring. There was no spring flush. Fortunately the few cattle that were there were being finished off in the yards, and fresh stock was not purchased until early May. Throughout the summer months the grassland made excellent growth, which was quite adequate for the stock.

The fields shut for hay grew rapidly in June after a slow start, but cutting was delayed by bad weather until the end of the month. The making of the hay was interrupted by the weather, but it was saved eventually in quite good condition.

Livestock

Cattle

The policy of buying in young store cattle and fattening them on the grass after overwintering in yards was continued. Owing to the drought in 1955 and the subsequent scarcity of keep, those bought in 1955 were not all sold by the end of that year. They were therefore finished off in the yards early in 1956. A fresh lot was bought fairly late in the spring, and throughout May there was just sufficient grass to keep them going. The plentiful supply of grass throughout the later summer months enabled them to be fattened and sold by the autumn, when a fresh lot of attested cattle was bought for overwintering. Altogether 27 cattle were sold fat during the year.

It is hoped to qualify for the Attested Herds Scheme in 1957, and to this end a first test was carried out in the autumn. There were no reactors.

Pigs

Following upon the rather disappointing results of 1955, the housing conditions have been considerably improved this year. In addition, the old stable has been converted into pig-fattening pens, three new farrowing pens have been made and four more are under construction.

Some of the older sows, and those with unsatisfactory records, have been disposed of. It is hoped to replace these by new stock early in 1957 and to build up the herd to about 20 sows.

These, and other changes, are bearing fruit, as the litter weights and numbers are already showing an improvement. It is confidently hoped that the full value of the improvements and the reorganization of the pig herd will be felt in 1957.

Staff

W. A. McCallum retired at the end of September after twenty-seven years' service as stockman and, for part of the time, as foreman.

WOBURN EXPERIMENTAL STATION

H. H. Mann

Season

The year 1956 brought a spring drought, a very wet summer and a damp but not very rainy autumn, while temperatures were low during the greater part of the year. In fact, after May, the mean maximum temperature for each month was considerably below normal as the following figures show:

Table 1

Mean maximum temperatures

	Normal, ° F.	1956, ° F.	Deficiency in 1956, ° F.
June	66·8	61·7	5·1
July	70·4	68·1	2·3
August	69·6	63·9	5·7
September	64·7	64·4	0·3
October	56·7	55·0	1·7
November	48·5	47·2	1·3

Low temperatures during the growing season had a serious effect on the yields of many crops, including both winter- and spring-sown cereals, and, especially, exotic crops which, in any case, are only

Table 2

Meteorological records for 1955–56

Month	Rainfall: Total fall, inches	Rainfall: No. of rainy days	Bright sunshine, hours	Temperature: Max., ° F.	Temperature: Min., ° F.	Temperature: 1 ft. in ground, ° F.	Temperature: Grass min., ° F.
1955							
October ...	1·79	13	116·1	55·5	40·4	49·4	36·0
November ...	1·26	14	52·1	49·6	37·5	43·9	32·8
December ...	2·28	20	61·1	48·0	35·4	41·0	31·9
1956							
January ...	3·98	21	62·8	43·3	32·0	37·5	29·5
February ...	0·54	11	66·0	35·5	22·7	33·6	22·1
March ...	0·77	7	149·5	50·6	34·5	40·6	29·1
April ...	1·35	8	148·6	52·4	33·8	45·0	29·8
May... ...	0·43	5	225·2	64·5	42·3	54·2	37·3
June ...	2·48	17	139·3	61·7	47·2	57·1	43·7
July... ...	3·69	13	162·6	68·1	52·5	62·1	49·7
August ...	4·19	22	146·4	63·9	49·1	58·1	46·6
September ...	2·16	11	98·8	64·4	50·4	56·9	47·5
October ...	1·50	15	108·4	55·0	41·0	49·6	38·2
November ...	0·75	11	66·8	47·2	35·9	41·9	32·7
December ...	2·93	21	20·1	39·1	37·8	41·0	34·3
Total or mean for 1956 ...	24·77	162	1,394·5	53·8	39·9	48·1	36·7

grown with difficulty in England. On the other hand, the heavy rainfall from June to September enabled root crops to give large yields. Grass was short in spring, rather too abundant in summer and more or less normal in autumn. The meteorological records from October 1955 to the end of 1956 are shown in Table 2.

Field Experiments

The field experiments at Woburn are now conducted under the direction of the Field Plots Committee at Rothamsted, and that committee will report on them separately so far as the yields are concerned. There are, however, a few points in connection with them that may be recorded here.

Permanent wheat and barley

The year 1956 is the eightieth since the Woburn Station was started in the autumn of 1876 with the permanent wheat and barley experiments, which still exist. On these plots no crop other than wheat or barley respectively has been grown, though there have been a number of years of fallow due to difficulties in controlling weeds, especially twitch grasses (*Agrostis gigantea*), which necessitated a period of rest to clean the land. In recent years there has, moreover, been an increase in acidity on almost all the plots on this lime-deficient land, and at present an attempt is being made to rectify this by applying carbonate of lime according to need, in order to bring all plots to about the original pH value of 6·0. At the same time, an attempt is being made to do away with twitch by treatment with trichloracetic acid. At present it is not clear how effective this is, but a preliminary test in June 1956 showed a decrease in the amount of twitch amounting up to 80 per cent. At the same time, there is the possibility that the land, by long cultivation with one crop, is losing its power to grow that crop even when sufficient manurial constituents are present. This suspicion was voiced by Russell in 1940 in his full account of the Rothamsted wheat experiments, published by the Commonwealth Bureau of Soil Science, and the following up of this line will be one of the great interests in the future of these experiments.

Potato root eelworm at Woburn

Among the rather disquieting features of 1956 has been the discovery that many of the fields where potatoes have been grown frequently are badly infected with potato-root eelworm (*Heterodera rostochiensis*). Already in 1955 its presence had unfortunate consequences in one of the blocks in the ley–arable experiment, and its abundance there led to an examination of most of the fields on the farm. Certain of the fields, notably Butt Furlong and Long Mead, were found to be so badly affected that no potato crop can be grown on them for several years to come. In other cases, the infection was very much slighter, and one experiment in Butt Close was laid out with potatoes. Unfortunately it proved to be infected in patches, and consequently it is very unlikely that reliable results will be obtained from the experiment. Arrangements have now been made for the intensive study of this pest by the Nematology

Department, and a special area of the farm has been allotted for the purpose apart from a general study of the increase or decrease of the pest on other areas.

Ley–arable and green-manuring

In two of the long-term experiments, namely those on green manuring and on the value of leys in maintaining the fertility of land, the results are now available for many years—in the former case from 1936 to 1953 and in the latter from 1938 to 1955. These results are now being worked up for complete publication. In the former case this is being done by D. A. Boyd and H. H. Mann, and in the latter by H. H. Mann. In the experiment on the value of leys in the maintenance of fertility, a number of fresh points have recently arisen, notably the question of potash exhaustion, and the investigation of this has been taken up intensively by the Chemistry Department at Rothamsted. The results so far available will be dealt with in the forthcoming publication on the green-manuring experiment, which will also deal with a number of points which have recently arisen suggesting that the moisture condition of the soil when green manures are buried and the percentage of nitrogen in the material used are perhaps the most vital factors in determining the value of green-manuring.

Relative effects of nitrogenous manures on grain and straw production

One interesting point has arisen from recent experiments on various quantities of nitrogen (as " Nitro-Chalk ") applied to spring wheat and barley. In these experiments, dressings of 2, 4 and 6 cwt. " Nitro-Chalk "/acre were applied to the crops, and the relative effect of the applications on the yield of grain and of straw were determined. In all cases it was found that while the increase in nitrogen always led to an increase in grain, there was at the same time a far larger increase in the amount of straw. In one experiment, for instance, it was found with spring wheat, taking the amount of grain as 100, the amount of straw was as follows :

No Nitrogen	133
2 cwt. " Nitro-Chalk "	154
4 cwt. " Nitro-Chalk "	169
6 cwt. " Nitro-Chalk "	180

These figures are based on samples drawn from the plots just previous to harvest. Similar results have been obtained with barley.

Irrigation experiment

In 1956 irrigation has been of little or no value, except in spring, when there was a drought after the barley was sown, and consequently the watered barley was distinctly better. The yields of barley grain are shown in Table 3.

There was thus an increased yield due to irrigation of 5·7 cwt./acre (25 per cent) with low nitrogen, and of 2·8 cwt./acre (9 per cent) with high nitrogen in this rather unusual season. It will also be noticed that irrigation has increased the proportion of straw.

The effect of irrigation on cut grass was almost confined to the

TABLE 3

Yield of barley

Treatment	Yield per acre, cwt.	Straw as percentage of grain
Not irrigated:		
Low nitrogen	22·4	83·5
High nitrogen	31·2	84·7
Irrigated:		
Low nitrogen	28·1	103·2
High nitrogen	34·0	116·6

spring, when there was drought; for the rest of the season it made little difference to the yield. This is shown by the following figures:

TABLE 4

Yield of grass

Treatment	Dry matter per acre: 1st cutting, 28 May, tons	Remaining 5 cuttings, 22 June to 19 November, tons	Total, tons
Not irrigated:			
Low nitrogen	0·70	2·08	2·78
High nitrogen	0·86	3·23	4·09
Irrigated:			
Low nitrogen	1·32	2·29	3·61
High nitrogen	1·55	3·43	4·98

The pure stand of cocksfoot which was sown three years ago is still very pure, and even the minor grasses with which it was contaminated have largely disappeared. The sward, which will apparently stand further years, has been left down for 1957.

Soils of the Woburn farm

On the Woburn farm there are two types of soil well represented, namely a light loam based on the Lower Greensand, on which most of the experiments have been and are being conducted, and a rather impervious silt soil overlying clay. On the former class of soil one of the very striking features has been the lack of response to potash or phosphate. This was shown by several experiments in 1956; but an experimental crop of beans on the heavier soil gave quite different results. Although phosphate gave no response, the effect of potash was very great on this land, for it produced an increase in grain of 45 per cent with a moderate dressing and even of 68 per cent with a high one.

New crops

The work of testing the suitability of some new crops for this country has continued, and the fact that 1956 had such a cold and

wet summer lent special interest to their behaviour under these circumstances.

Maize

In the last report it was noted that for a period of seven years it had been possible to get a mean yield of 34·7 cwt./acre of grain from hybrid maize, using seed obtained in the early years from Wisconsin (U.S.A.) and more recently from Holland. This made the growing of maize for grain under suitable conditions a practical proposition, at least for smallholders. It was therefore of special interest to see how far the crop would stand up to the cold and wet conditions in 1956, using seed of the best Dutch variety (Prior). The seed was sown on 28 April, and the crop was harvested from 16 October to 29 November. In spite of the cold, wet summer, it grew well, but was late in forming ears, and although they were small, in the end there were 1·47 ears per plant. In the damp autumn harvesting was late and difficult and the grain had to be artificially dried. A yield of 14·9 cwt./acre of dry grain was obtained, which is less than half the mean yield of the previous seven crops. Though this does not necessarily condemn the crop for local use, it shows that, while a normal crop of over 30 cwt./acre can be usually obtained, a much smaller yield in at least one year in eight may be expected.

Soya beans

If the cold summer gave a small crop of maize, its effect on soya beans was much worse. The few rows which were grown in 1956 never came to seed, and confirmed the conclusion (recorded in the last report) that soya beans seem to have little future in this country.

Fodder crops

Sweet lupins. The suitability of sweet lupins for semi-acid soils such as those at Woburn is now clear, and 1956 has shown that they can do well in a wet summer, when grown for fodder to be used in September or October. On this point we now have records for every year since 1951 :

TABLE 5

Yield of sweet lupins

Year	Green stuff per acre, tons	Dry matter, %	Dry matter per acre, tons
1951	14·1	12·6	1·70
1952	15·7	12·1	1·90
1953	27·8	12·4	3·45
1954	16·1	9·6	1·55
1955	3·0	14·9	0·45
1956	20·8	13·1	2·77
Mean	16·3	12·5	1·97

These figures suggest that on soil similar to that at Woburn, namely a light or sandy loam slightly acid (pH 6·0 or less) in fairly good agricultural condition, an average yield of over 15 tons of green fodder can be obtained in September. Tests showed that about

25 per cent or more of this would be inedible. In a wet summer the yield may be much higher than this, but in such seasons there will be little or no good seed. By reaping earlier the percentage of inedible matter could be decreased, but with a corresponding loss of yield. It appears that there is a great opening for growing sweet lupins as a fodder crop on suitable land in this country.

Serradella. The same adaptation to acid soils has been found with serradella, which has been grown for a number of years as a fodder crop for use in September when grass is beginning to fail. The seed used at Woburn was originally obtained from the U.S.A., but it has been possible to maintain our area with home-grown seed obtained in the drier years. This crop contrasts with sweet lupins in that it is eaten greedily by all classes of stock. In wet years, such as 1954 and 1956, it gave large yields of green stuff in September, especially in 1956, when 30·16 tons/acre were grown containing 10·9 per cent dry matter, or 3·29 tons/acre of dry forage. On the other hand, no seed was obtained in 1956, while in the dry season of 1955 it was abundant and of good quality.

Birdsfoot trefoil. Types of birdsfoot trefoil developed in the U.S.A. have roused much interest in recent years. An advantage is that they will grow on poorer land than clover and give a good yield of fodder, particularly in the latter part of the season, for at least three and possibly more years. The crop was grown at Woburn from 1952 to 1954 in two varieties, and gave very good yields in the latter part of the year of sowing, very high yields in the second year and moderate produce in the third year, when, however, the crop became overrun with grass. It was found that the crop grew very slowly in early summer but abundantly after the middle of July.

A new consignment of seed was obtained in 1956, and, though it came very late, it was sown in the middle of June. It grew slowly at first, but vigorously after July. When cut on 23 October it gave 4·7 tons green stuff/acre containing 16·6 per cent dry matter or 0·77 tons dry matter/acre. It has now been left for a second year. These American improved types of birdsfoot trefoil seem to have prospects as fodder crops in this country.

Jerusalem artichokes. Last year's report contained an account of the first two years of experiments with an improved type of Jerusalem artichoke introduced into this country from Germany under the name "Topine". Tests with this crop have been continued in 1956, and in the very different conditions of the three years in question we have obtained yields as follows :

TABLE 6

Yield of Jerusalem artichokes

	Artichoke tops			Artichoke tubers	
	Green stuff per acre, tons	Dry matter, %	Dry matter per acre, tons	Per acre, tons	Per plant, lb.
1954	17·6	18·8	3·34	8·5	0·73
1955	9·4	30·1	2·82	14·5	1·50
1956	14·1	22·2	3·12	13·5	—
Mean (3 years) ...	13·7		3·09	12·2	

Since artichokes would be most useful as pig food, the results were compared with an adjoining plot of Majestic potatoes, similarly manured with a dressing of 10 cwt./acre of potato fertilizer. A yield of 19·8 tons of potatoes/acre was obtained, and this yield must be compared with those given above for the artichokes. In the latter case it is presumed that the artichoke tops would be converted into silage after being torn up in a suitable machine.

On the whole, it can be said that the crop, in the special luxuriant types now available, is promising. Only further trials can determine its ultimate utility in British agriculture.

Laboratory Work

The laboratory work at Woburn is almost exclusively related to the field experiments and has, in 1956, been very largely taken up with the analysis of soil and produce from the ley–arable experiment, and with the determination of the permanence of organic matter added to soil, as farmyard manure, sewage sludge and composts. The results will be included in reports of the various experiments involving these materials.

The work in the laboratory has fallen almost entirely on Mr. Barnes, the chemist to the Station, and his staff, and they have been fully employed in this and other directions during the year.

TROPICAL SOILS

H. GREENE

Cecil Frederick Charter died in London after a brief illness on 27 January 1956. He was then director of the Soil and Land-Use Survey in the Gold Coast. That country has lost a good friend and an outstanding scientist. We have also to record with deep regret the untimely death on 7 April 1956 of Vivian John Weston, a member of the soil-survey staff in Nigeria.

The need for soil surveyors in British territories overseas has been recognized by creation of a pool of six soil surveyors, of whom four are associated with Rothamsted. During 1956 A. O. Ballantyne has continued his work in Northern Rhodesia and G. F. M. Murdoch has been surveying land for irrigation in Swaziland. J. Stark has been seconded to British Guiana for two years, and will be working with T. A. Jones and other members of the team supplied by the Caribbean Regional Research Centre. Mr. R. F. Loxton of the University College of the Gold Coast spent some months with this team and has made an interim report on the survey of the Rupunnuni savannah. In preparation for secondment to Sierra Leone J. C. Chisnall, another member of the pool, has spent six months in the swampy coastal region of British Guiana. He was working with soil surveyors supplied by the University of Maryland under contract with the International Co-operation Administration of the U.S.A. Two members of the pool of soil surveyors, C. Grant and D. M. Lang, are associated with the Macaulay Institute, and have been training under Dr. R. Glentworth. C. Grant has been seconded for two years to Hong Kong, being accompanied at the start by Dr. Glentworth; D. M. Lang has begun soil survey in Malta in support of the geographical studies being made there under direction of Professor H. B. Fisher of the University of Durham. D. A. Osmond briefly visited Malta to give Lang a flying start. It is hoped to recruit a chemist as seventh member of the pool of soil surveyors and to give to some members of the pool additional training in irrigation problems.

After training in the Chemistry Department at Rothamsted, R. K. Cunningham has joined the staff of the West African Cocoa Research Institute and A. Pinkerton is about to begin his duties with the Department of Agriculture in Kenya.

Mr. D. Rhind of the Colonial Office and H. Greene visited British Guiana in February 1956 and were shown the notable improvement of pasture at Ebini following application of basic slag to the impoverished soil of the white sand sediments. The work was in charge of Mr. J. R. Goode, who had been supplied by the Food and Agriculture Organization of the United Nations. His observations confirm analyses of fodder and of soil samples that had been carried out at Rothamsted. Sugar cane and rice are grown in British Guiana on the more recent coastal sediments, consisting of marine clay with some peat. H. Paul and J. K. R. Gasser have obtained

important responses to phosphate by rice when grown on the more acid, peaty soils. There was an indication, not yet confirmed, that the sulphate of ammonium sulphate reduced yields of rice.

H. Greene also visited Trinidad, British Honduras and Jamaica. Discussions in Trinidad led to agreement that rehabilitation of non-swampy areas, more detailed soil survey and improvement in the physical condition of the soil called for urgent attention and additional staff. In British Honduras one can still see striking responses to phosphate obtained in small experiments laid down by A. C. S. Wright of the New Zealand Soil Bureau and D. H. Romney. Their example has been followed with success in some poorly-drained acid soils of Trinidad also. There is need in British Honduras for extension of this work; it is thought that pastures offer promise. Very satisfactory progress has been made in the soil survey of Jamaica by the close and successful co-operation between men supplied by the Jamaica Department of Agriculture and by the Caribbean Regional Research Centre. In Jamaica the work is led by C. W. Hewitt and K. C. Vernon respectively. A new set of aerial photographs will facilitate the work and the recording of data; although the need for rehabilitation of upland areas is urgent, there is also need for vigilant scrutiny of recommendations made to peasant farmers. It is a case of more haste, less speed, for the upland areas have not yet received detailed investigation comparable to that given to the fertile lowland areas.

The British tax-payer seems to be getting good value for the considerable sums of money allocated for the Caribbean Regional Research Centre. In Trinidad cocoa has continued to present many problems, including soil problems. An excellent series of reports is being issued. Information of lasting value may be expected from spectrographic analysis and from the statistics section, to which G. E. Hodnett has been appointed.

E. W. Russell was chairman of Commission IV (soil fertility) and H. C. Pereira was vice-chairman of Commission I (soil physics) at the Sixth Congress of the International Society of Soil Science (Paris, 29 August–8 September 1956). The printed transactions include papers by B. Anderson, W. E. Calton, W. N. M. Foster, J. K. R. Gasser, D. J. Greenland, T. A. Jones, J. S. G. McCulloch, P. H. Nye, W. P. Panton, H. Paul, C. J. Piggott and J. W. Vail. Some other papers from British territories overseas will appear in a later volume of the Transactions of the Congress.

J. P. Fox of the New Zealand Soil Bureau has made a draft report on the soils of Viti Levu, the largest of the Fiji islands. There has been progress also with soil survey in North Borneo (T. R. Paton; A. W. Allen) and in Malaya (A. R. McWalter; W. P. Panton). Several memoirs have been issued from the Gold Coast (H. Bramner, C. F. Charter, A. J. Crosbie, R. Hamilton, J. M. Hotson, M. F. Purnell, S. A. Radwanski).

Among studies of soil fertility involving various crops the following may be mentioned: rice in Zanzibar (G. E. Tidbury); maize in Basutoland (A. C. Venn); ground nuts in Sierra Leone (C. J. Piggott); cocoa in Trinidad (G. A. Havord, G. K. Maliphant, F. W. Cope); sugar cane in British Guiana (H. Evans); sugar cane in Jamaica (R. F. Innes, T. Chinloy); pine-apples in Kenya (J. B. D.

Robinson). Micronutrients have been receiving attention in Uganda (E. M. Chenery), in Tanganyika (W. E. Calton) and in the Gambia (R. A. Webb). Elaborate fertilizer experiments with oil palm in West Africa have been discussed by W. B. Haines and Blanche Benzian. There are also valuable reports from the West African Institute for Oil Palm Research.

In the severely eroded island of St. Helena preparations are being made for spray irrigation of a small area. During the past few years remarkable success has been achieved in the Abyan irrigation scheme in Aden Protectorate, but some severe difficulties have yet to be overcome. J. E. A. Ogborn has begun to study the water-logging and salinity that affect part of the irrigated area.

In October 1956 H. Greene visited Australia to attend the symposium on arid-zone climatology organized jointly by the Commonwealth Industrial and Scientific Research Organization and by the United Nations Educational Scientific and Cultural Organization. In Australia conservation of water is of obvious importance. Since evaporation from plants and soil depends on air movement near ground level, great interest was shown in the detailed studies of turbulent transfer that are being carried out by the Australian Division of Meteorological Physics. There was discussion also on the physiological factors, possibly genetic, that enable animals to withstand heat and drought. Experiments are in progress on the use of cetyl alcohol to reduce evaporation from reservoirs.

Returning from Australia, H. Greene visited North Borneo, Sarawak and Aden. In Sarawak Mr. T. W. G. Dames, who was supplied by the Food and Agriculture Organization of the United Nations, has been studying humus podzols under poor forest vegetation. Plans are being made for additional soil-survey and fertility studies in Sarawak.

SOIL SURVEY OF ENGLAND AND WALES

D. A. Osmond

The area mapped shows a slight decrease compared with that in 1954–55 because maps and memoirs were being prepared for publication, but, even so, about 250 sq. miles have been surveyed. Two further sheets have been completed, new work on Sheet 19 (Hexham) undertaken and survey has been continued in the areas previously recorded. With the completion of Sheets 94 (Llandudno) and 106 (Bangor), the centre at Bangor has been closed and the surveyor transferred to Cardiff.

Two members of the staff have resigned: J. F. Harrop joined the Soil Survey of Uganda and L. F. Curtis accepted an appointment in the Geography Department at Bristol University. Both will be missed, for they were competent surveyors and very much liked by their colleagues. The vacancies have been filled, and two additional surveyors, E. M. Bridges and C. P. Burnham, have been appointed. Miss A. M. Du Feu was appointed to assist with clay mineral studies. In addition, R. R. Storrier and J. Loveday, both from Australia, are working with the Soil Survey, the former has mapped soils developed on the Ironstone near Banbury, and the latter will be working on the soils of the district around Henley-on-Thames. J. Stark has been appointed to the Colonial Pool of Soil Surveyors and is working in British Guiana, A. O. Ballantyne and G. F. M. Murdoch are still working in Northern Rhodesia and Swaziland respectively. C. A. H. Hodge has returned from Somaliland to his duties in Cambridge. R. S. Seale and A. J. Thomasson have been given leave to continue survey work on an irrigation project in Iraq. D. A. Osmond spent a short time in Malta with D. M. Lang, who is making a survey of the island.

A. Muir attended the 6th International Congress of Soil Science at Paris and acted as Chairman of Commission V (Genesis and Cartography). B. W. Avery (who presented a paper), D. C. Findlay and A. Crompton also attended and, with A. Muir, participated in the Post-Congress tours of Eastern and South-eastern France.

Members of the Soil Survey organized a highly successful excursion to the Chilterns and Vale of Aylesbury for the British Society of Soil Science.

Northumberland

Sheet 19 (Hexham)

The work may be broadly divided into two phases, preliminary examination of soils and parent materials on Sheet 77 (Hexham, New Popular Edn.) and, later, detailed surveying at 6 inches to 1 mile scale on Sheet 19 (Hexham, 3rd edn.).

The early examination showed that glacial drift of widely differing origins is common, and only occasionally are the underlying

rocks exposed or thinly covered with drift; consequently, even apparently sedentary soils are drift-contaminated. Over large areas the drift appears to be locally derived, but there are four other major deposits of till. Two drifts have encroached from the east, a drab grey, generally arenaceous till that is frequently overlain by a dark reddish-brown till of heavier texture. In the north, ice from the Cheviot Massif has been responsible for patches of drift in part derived from the Old Red Sandstone and associated measures. To the south, the Tyne Gap formed a relatively easy path for western ice to bring till from the Trias west of the Pennines and erratics from the Lake District and the Southern Uplands of Scotland.

The traverses on Sheet 19 are south of the Tyne Valley and run on a N.N.E.–S.S.W. line crossing the direction of ice-flow and the grain of the underlying strata of the Millstone Grit and the Scottish Carboniferous Series. The climate is of fundamental importance, and it appears that below 800 feet the soil-forming processes are critically balanced between podzolization and gleying. Frequently a change of process is noticeable with a change of management.

Several series have been recognized and mapped, and it is hoped to complete the traverses soon. (G. D. Ashley and C. C. Rudeforth.)

Yorkshire

Sheet 70 (Leeds)

The centre has been engaged on the final stages of the mapping of this sheet on the 6-inch scale. Early in the season an area was surveyed east of Leeds, where the soils are formed on Coal Measures little influenced by glacial drift. The dominant soil is formed on the Coal Measures Shale and is imperfectly drained. It is highly prized for specialized horticultural crops, notably rhubarb, flowering broccoli and, to a smaller extent, raspberries, strawberries and wallflowers.

The later part of the season was spent on the fluvio-glacial and lacustrine deposits in the Vale of York, mainly near Church Fenton. The alluvium of the lower Wharfe presented interesting problems. The deposited silt is highly calcareous, but those parts of the alluvial plain that are protected from flooding by embankments have become leached and have a history of progressively decreasing value as grazing land. The old and formerly well-founded tradition that these soils do not need liming has tended to discourage the application of lime after the need for it has become well marked. (A. Crompton and C. B. Crampton.)

Lancashire

Sheets 74 (Southport) and 83 (Formby)

The mapping of Sheet 74, comprising 44 sq. miles, is complete, and work is proceeding on Sheet 83. The mineral soils are mainly derived either from heavy-textured Triassic till, Shirdley Hill Sand or Estuarine–Freshwater Alluvium, and all correspond with those described from Sheet 75 (Preston). The substantial areas of peat have been mapped by systematic traverses, and it has been found that their depth ranges from a few inches to 20 feet. The peats are

of the Azonal type and developed initially under the influence of ground-water in basins and low-lying areas. Two main types of Basin Peat occur at the Low Moor Stage—Eutrophic and Oligotrophic—and a later stage of development under ombrogenous conditions has resulted in small areas approaching Raised Bog. The peats have been grouped into four main classes on their structural properties and botanical composition.

Grass–sedge peat. Eutrophic to mesotrophic basin peat which prior to draining and cultivation had reached a stable stage of Low Moor. Generally light coloured and of a fibrous texture, there are, however, marked variations due to local conditions.

Sphagnum–eriophorum peat. The depth of this generally fibrous peat rarely exceeds 2–3 feet, it is yellowish to reddish brown in colour and overlies grass–sedge peat. It represents peat growth from the period when the surface layers of eutrophic–mesotrophic basin peat rose above the influence of ground-water and further accumulation occurred under ombrogenous conditions. The marked change in vegetation often indicates development from Low Moor to pre-Raised Moss stage.

Eriophorum peat. This peat is generally dark brown in colour, has a tough fibrous texture and is oligotrophic throughout. The upper layers are often a mixture primarily composed of *Eriophorum* spp. associated with *Sphagnum* spp. and *Calluna vulgaris*.

Martin Mere peat. Silty, dark brown, amorphous peat with laminae of fine sand and silt. The organic fraction, derived from decomposing vegetation mixed with fine sand and silt, probably accumulated as a mud on the bed of the one-time lake. (B. R. Hall.)

Caernarvonshire

Sheets 94 (Llandudno) and 106 (Bangor)

The mapping of these sheets has been practically completed. The coastal strip had been mapped in detail in pre-war years, and only a few modifications have been necessary. Mapping was carried out along the western slopes of the Conway valley and extended into the foothills of the northern block of Snowdonia. Here a progressive admixture of igneous material, mainly acidic, somewhat modifies the soils from those derived purely from Ordovician and Silurian shales to the east. The change is gradual and somewhat capricious in such a strongly glaciated area of complex geology, and the little agricultural use made of these rather inaccessible foothills with high rainfall does not justify the labour of carefully separating soils of progressively greater admixture. Only soils of dominantly igneous origin have been separated from those developed on shales. In the mountains a reconnaissance survey gave a broad picture of the distribution of brown podzolic soils, peaty podzols, peaty gleys, peats and rock-dominant areas.

Much of the season was occupied with work on the memoir for Sheets 95 (Rhyl) and 107 (Denbigh), and some further sampling and local study was needed to clarify a few points. (D. F. Ball and J. F. Harrop.)

Derbyshire

Sheet 125 (Derby)

Several outbreaks of foot-and-mouth disease occurred in this area during August and September. At the request of the Provincial Director of the National Agricultural Advisory Service, and to avoid any risk of spreading the disease, surveying was discontinued for six weeks. As a result, the area surveyed, 45 sq. miles, was less than originally planned.

Mapping was mainly confined to the west of the Derwent, where parent materials of Triassic and Carboniferous ages occur. The variation in parent material was found to be reflected not only in the soil morphology but also in the resulting agricultural pattern. Lithological differences, combined with small changes in relief and climate, have led to the formation, in the main, of brown earths of high base status in the Triassic area, while brown earths of low base status, peaty podzols and gley soils characterize the Carboniferous area. (J. H. James, L. F. Curtis and J. P. Watson.)

Shropshire

Sheet 166 (Church Stretton)

Surveys have been made of two principal geological areas: (1) the Uriconian Hills and associated Lower Palaeozoic sediments, and (2) the Old Red Sandstone beds of Corvedale and the Dittonian Platform. Of the 26 sq. miles mapped, approximately 13 sq. miles have been completed in each district.

The Uriconian Hills of Caer Caradoc, Lawley, Ragleth and Hope Bowdler are generally steep-sided, and the soils are shallow, light-textured brown earths. Flanking the lower slopes are the more readily weathered Lower Palaeozoic sandstones and shales on which deeper soils are found, and the gentler slopes encourage arable cultivation. Where, however, shales are dominant, the soils are gleyed and good field drainage is essential. Small isolated patches of northern drift (a common deposit on the lower ground) are found at 1,000 feet and are testimony to its former wider extent.

Mapping in Lower Corvedale is not complete, but a complex series of east–west alluvial channels has been found linking the alluvial flats of the Corve and Pye Brook with deep indentations in the Dittonian escarpment. The soils developed on alluvium vary greatly in texture, but generally are not gleyed. Soils derived from the Ledbury marls, underlying the alluvium and exposed only in isolated ridges and hills, have the general characteristics of the Bromyard series, although the parent material is highly calcareous. (D. Mackney.)

Cambridgeshire

Sheet 173 (Ely)

One member of the team was seconded to the Somaliland Government for six months and returned to the United Kingdom in April to write a report on the work. The examination of thin sections and mineralogical preparations, as well as the preparation of the map and memoir of Sheet 188 (Cambridge), has occupied a consider-

able amount of time, and for the greater part of the year only one surveyor has been working on Sheet 173, of which about 10 sq. miles north of Isleham have been surveyed. Here peat soils developed on the " fen clay ", an estuarine deposit interbedded in the peat, were encountered for the first time. Other soils include the Worlington series on a light, sandy parent material and complex areas of sand soils and peats. (C. A. H. Hodge and R. S. Seale.)

Oxfordshire

Sheet 201 (Banbury)

A detailed reconnaissance survey of 36 sq. miles between Banbury and Edge Hill in North Oxfordshire has been completed, using air-photos as base maps. The area is characterized by a moderately dissected plateau of Middle Lias ironstone, which gives rise to a uniform soil type corresponding to Kubiena's Ferritic Braunerde. The soils in the valleys are developed on ironstone colluvium and Middle and Lower Lias silts and clays. Several soil types named by G. R. Clarke on Sheet 218, which adjoins, have been mapped in the area. (R. R. Storrier.)

Hertfordshire and Buckinghamshire

Sheet 238 (Aylesbury)

Extensive revision of earlier work has been undertaken, and fifty-two representative profiles have been described and sampled for analysis. A 2½-inch map of the sheet is being prepared; this enables the soil pattern to be seen more effectively than the 6-inch field slips and facilitates the final reduction to the publication scale of 1 inch to 1 mile. (B. W. Avery, D. W. King and A. J. Thomasson.)

Somerset

Sheet 280 (Wells)

Forty sq. miles were mapped along the northern margin between Congresbury and Chew Stoke and in the area between Compton Martin and Paulton. Apart from isolated Lias-capped hills, the geological formations are mainly of the Keuper, consisting of marls in the west and becoming gradually more sandy in an easterly direction.

In the Vale of Wrington, where gravels derived from the Mendip Hills overlie the marl, the Langford series occurs where the gravel is thick and drainage is free. Around Stock and Brinsea these deposits become thin and two gley soils occur—an imperfectly to poorly drained sandy loam and a poorly to very poorly drained heavier-textured soil with a peaty surface in places. Similar soils were found around Ubley, where cherty gravel overlies the marl. East of Butcombe and Ubley, where the Keuper formation contains more fine sandy bands, freely drained soils resembling the Hodnet series of the Midlands occur, together with a poorly drained counterpart on flat and depressed sites. Approaching the Coal Measures outcrops around Temple Cloud, the Keuper formation becomes more sandy and bright red in colour. It may be possible to correlate the

deep, freely drained soil developed with a soil also described from the Midlands. (D. C. Findlay and B. Clayden.)

Kent

Sheet 305 (Folkestone)

Surveying was continued to Guldeford Level and the remainder of Wallend Marsh, together comprising about 30 sq. miles. These are the younger parts of Romney Marsh, reclaimed piecemeal over many centuries, and an initial rapid survey of innings walls and natural features, such as creeks, fleets and channels, yielded information regarding the genesis and historical development of the area which greatly facilitated later work. Man and Nature have influenced each other to a marked degree, and the features mentioned are important in determining the relief and the deposition of deposits of widely different texture. Several score miles of innings walls were tracked and mapped, many of them proving to be important soil boundaries. This phase was followed by semi-reconnaissance soil mapping, and all but a few thousand acres have now been surveyed on this basis. (R. D. Green.)

Other Work

A reconnaissance map of the soils of Guernsey was prepared at the request of the Horticultural Officer. Four soil regions were recognized on a topographical basis. Generally, the higher parts are covered by "limon", giving rise to freely drained loams, silty where the deposit is thick and gritty where it is directly influenced by the underlying metamorphic rocks. Below 75 feet O.D. fine, sandy soils are associated with old raised beaches passing, nearer the sea, to a littoral zone characterized by wet, coarse sandy soils and small areas of peat. (D. W. King.)

The sites of thirty-one field experiments carried out on commercial farms by the Chemistry Department were examined with a view to characterizing and classifying the soils. (B. W. Avery, D. W. King, A. J. Thomasson, L. F. Curtis and C. A. H. Hodge.)

An excursion to the Chilterns and the Vale of Aylesbury was organized in connection with the Summer Conference at Reading of the British Society of Soil Science. (B. W. Avery, D. W. King, A. J. Thomasson and C. L. Bascomb.)

A survey was made of a large commercial farm on which fertilizer experiments are to be laid out at Levington, Suffolk. (C. A. H. Hodge and R. S. Seale.)

Work has continued on the weathering of limestone. Early results suggest a relationship between the size of the block, the absorption expressed as a percentage of dry weight and the amount of shattering. (J. H. James.)

At the request of the National Agricultural Advisory Service observations on soil structure and other aspects of soil formation were made on restored ironstone workings. Advice was also given on water supplies to the Drainage and Water Supplies Division of the Derbyshire Agricultural Executive Committee. (J. H. James.)

Several profile examinations and some experiments have been

made on clay soils found, by Dr. E. C. Childs and his colleagues, to be highly permeable with regard to ground-water. Some crop-yield experiments have been carried out on two soils under identical management. Water-table levels have been regularly measured for a variety of soils. (R. D. Green.)

SOIL STRUCTURE

By

W. W. Emerson

Introduction

The basic problem of soil structure consists in finding out how the individual constituents of soil crumbs, such as sand, clay and organic matter, are bonded together. The nature and number of these bonds will determine the strength of the crumbs. This, in turn, will decide if the surface soil pans under the mechanical action of falling raindrops, whether the soil is free draining and the ease of cultivation. The Physics Department has been particularly interested in the improvement of the structure of clay soils after a period under grass. One of the improvements is known to be an increase in the resistance of the crumbs to breakdown in water, and the problem has been to measure this increase in such a way as to offer some clue as to the mechanism by which it is brought about.

Previous workers have used two main methods. In the first, originated by Tiulin (1928), the dry crumbs were placed on top of a bank of sieves, wetted and the size distribution of the wetted crumbs determined after agitating the sieves under water. The second way, due to Middleton (1931), instead of reducing mechanical breakdown after wetting to a minimum, measures the degree of dispersion produced by a given amount of mechanical action. This is usually done by shaking the crumbs in water in an end-over-end shaker for a fixed time. There are two causes of crumb breakdown in both these methods : the initial breakdown on wetting the air-dry crumbs with water, usually called slaking, and the subsequent mechanical attrition of the crumbs. Slaking is due both to swelling of the clay on wetting, which may in extreme cases lead to dispersion of the clay, and also to the explosive action of entrapped air. The severity of the initial breakdown of the crumbs will clearly depend on the rate of wetting, and this was the first aspect of crumb breakdown which was investigated (Emerson and Grundy, 1954).

Crumb Breakdown Due to Slaking

Columns of soil about 8 cm. high consisting of 2–5 mm. air-dry crumbs were wetted with distilled water at different rates by means of capillary-tube siphons of different diameter. Check columns were also wetted under vacuum, which would prevent breakdown due to entrapped air. The cohesion of the wet crumbs was determined by measuring the height from which 40 drops of water would cause 0·15 g. out of approximately 1 g. of the wet crumbs to pass through a 1·2-mm.-aperture gauze. This technique was sufficiently gentle to avoid breakdown of the crumbs due to dispersion of the clay, and merely fractured the crumbs along planes of weakness produced during the initial wetting. Samples were taken from two adjoining

plots on the Rothamsted Farm, containing 30 per cent clay, one under permanent grass and the other permanent arable which receives 14 tons dung/acre annually. The results showed that cohesion decreased sharply with rate of wetting, as expected, the decrease being more pronounced with the arable compared with the grassland crumbs. However, when wet at 0·2 cm./hr. rainfall, which is not often exceeded under the low-intensity rainfall in this part of England, the cohesion of the crumbs was not much lower than those wet under vacuum or extremely slowly. It was concluded, therefore, that slaking is not an important cause of crumb breakdown for this soil with these cropping treatments. This result is not generally valid, and slaking may be very severe with lighter soils. Extrapolating back to zero rate of wetting, the strength of the grassland crumbs was about twice that of the arable crumbs, showing that there must be an additional cohesive force present in the former.

Swelling of Soil Crumbs

A by-product of the preceding work was to demonstrate that the amount of water held by a soil at low suctions (up to about 200 cm. water) depended both on the rate at which the soil was wetted, because with rapid wetting more water could be accommodated along the planes of failure and, indirectly, on the length of time the soil was wet, because the swelling of the clay was found to take at least 24 hours. This latter point was later investigated in more detail (Emerson, 1955a). A clay crumb which had been dried to the wilting point (pF 4·2) was suspended on one arm of an analytical balance and slowly wetted using a capillary siphon, care being taken to prevent evaporation from the crumb. Although the crumb appeared to be completely wet after the first drop had appeared on the base of the crumb, in fact the crumb continued to increase in weight and was still doing so very slowly when the experiment was discontinued at the end of three months. Approximately 75 per cent of the total water uptake occurred in the initial wetting. Besides modifying the concept of field capacity, these results have an important bearing on the drainage of heavy clay soils when water percolates to the drains through fissures in the subsoil. The fissures will slowly close up during the winter as the clay swells, and since conduction depends on the fourth power of the radius, a small decrease in size will have a considerable effect on permeability. The more the subsoil is dried out during the summer, the more rapid will be the drainage the ensuing winter. One of the better crops for this purpose would be wheat, and the worst treatment a summer fallow. An analysis of Mr. Nicholson's results on the running of the mole drains on the Cambridge University Farm demonstrated this dependence of drain performance on summer cropping very elegantly.

Wet Strength of Crumbs

The next step was to investigate the second cause of crumb breakdown, i.e. disintegration of the wet crumbs. The two methods mentioned at the beginning determined the resistance of the wet

crumbs to mechanical action, but it was thought that more controllable results might be obtained by using a " chemical hammer " on the crumbs in the following way. If two negatively charged plates (idealized clay crystals) are immersed in a salt solution there is a repulsive pressure between the plates due to the higher salt concentration between the plates than in the equilibrium solution outside, and this pressure increases as the salt concentration is reduced if the plates are a fixed distance apart. The pressure may be calculated using the simple Gouy theory, provided the plates are far enough apart. Therefore, by bringing crumbs into equilibrium with increasingly dilute salt solutions the weaker the attractive forces between the clay crystals, the greater will be the distance the crystals are forced apart, until eventually the crumbs fail and disperse. Unfortunately in the case of calcium saturated crumbs, which is effectively the English condition, the intrinsic short-range attractive forces between the clay crystals are sufficiently strong for the crumbs to remain stable even when percolated with distilled water. In water the calcium clay in the crumbs is in a metastable state of equilibrium, because if the crumbs are shaken the clay disperses, and a concentration of about 3 m*M*. $CaCl_2$ is needed before the clay will reflocculate. However, it was known that montmorillonite saturated with sodium would swell up spontaneously when brought into equilibrium with decreasing concentrations of sodium chloride (Hofmann and Bilke, 1936) until at a finite concentration of about 15 m*N*. the clay dispersed. This suggested that if the crumbs were first sodium saturated differences in the attractive forces between crumbs would be brought out.

In the initial experiments (Emerson, 1954a) a 1-cm. bed of 1–2 mm. air-dry crumbs was wetted with 500 m*N*. NaCl slowly under suction on a sintered-glass funnel to avoid breakdown due to slaking. After percolating with 500 m*N*. NaCl to displace all other exchangeable cations, successively more dilute salt solutions were percolated through, maintaining a constant hydrostatic head, and the decreases in permeability measured as functions of salt concentration in the leachate. The method was tried first on the Barnfield soil used in the earlier rate-of-wetting experiments. Two plots on Barnfield itself, 80, the unmanured plot, and 2N, receiving 14 tons dung annually, were compared with adjoining permanent grass, i.e., the same mineral constituents but different amounts of organic matter. The crumbs from 80 dispersed completely in 30 m*N*. NaCl, those from 2N in 5 m*N*., whereas the permeability of the grassland crumbs was still appreciable when percolated with distilled water. By contrast, on shaking the sodium-saturated crumbs into suspension it was found that the flocculating concentration of NaCl for the 80 plot was about the same as the dispersion concentration, but in the case of the grassland and 2N plots it was considerably higher, namely 250 m*N*. The organic matter present in the soil could therefore act both as a cementing agent for the flocculated clay in the crumbs and as a peptizer if the clay was brought into suspension.

In attempting to refine the technique it was found that an important part of the measured decrease in permeability was due to blockage of the pores in the sintered-glass funnel by dispersed clay and silt. This difficulty persisted even with coarser funnels, and it

has only recently been overcome. In the method of test at present, a bed of 1–½-mm. glass spheres has been substituted for the sinter and the crumbs are brought into equilibrium with one concentration of NaCl only, namely 50 m*N*. At this concentration the Barnfield 80 crumbs, the weakest possible crumbs, collapse to form an impermeable bed, but no dispersed clay actually appears in the leachate, whereas the permeability of the corresponding permanent-grass crumbs remains unchanged.

To recapitulate, one of the reasons for developing the sodium method was to distinguish increased crumb stability, due to a slower rate of wetting when the crumbs are immersed in water, and a genuine increase, due to stronger attractive forces between the clay crystals in the crumbs. The former effect can be achieved by coating the crumbs with any substance which increases the contact angle of the crumbs with water.

Nature of the Organic Clay Complex

To obtain some insight into the way in which the organic matter stabilized the crumbs even after Na-saturation, the stabilization of crumbs and also pure clays by various substances of known chemical composition was investigated, since the organic matter appeared to stabilize the clay specifically (Emerson, 1956a). The first substances investigated were the polymers marketed for stabilizing crumbs, known as soil conditioners. These are of two kinds : the non-ionic polymers and carboxylated polymers. The simplest of the first is polyvinyl alcohol (PVA), repeating unit $-CH_2-CH(OH)-$, but natural substances such as dextrans may also be used. The second may be either of the linear ethylenic type, the simplest being polyacrylic acid (PAA), repeating unit $-CH_2-CH(COOH)-$, or polyuronides, such as sodium alginate or carboxymethyl cellulose. Small quantities of these substances in solution were mixed with Barnfield 80 soil to form a paste, which was then pushed through a 3-mm. sieve and finally dried to form synthetic crumbs. It was found that about 0·5 per cent by weight of polymer would confer maximum stability on the crumbs, i.e., no decrease in permeability occurred after percolating *N*/20-NaCl for 24 hours. The one exception was sodium alginate, which was only effective on soil which had been sodium saturated initially. This was ascribed to precipitation of the alginate as calcium alginate before it could become attached to the clay.

It was found that when crumbs stabilized with PVA and PAA were placed in water, after saturating with sodium, the former remained unaltered, whereas the latter swelled considerably. Flakes of Na-clay, to which small quantities of the two polymers had been added, behaved similarly (Emerson, 1955b). PAA was also effective at much lower concentrations than PVA. In particular for montmorillonite (Wyoming bentonite), 4 per cent PVA but only 0·25 per cent PAA were necessary to form stable Na-gels in water. By X-ray measurement of the dry flakes it was shown that PVA was linked to the planar faces of the crystallites to form an interlamellar complex. Unfortunately in the case of PAA, although an X-ray photograph of the dry flake was the same as an untreated

flake, this was not sufficient evidence to infer that an interlamellar complex had not been formed, as there may have been insufficient regularly arranged crystals to give an X-ray reflexion. The carboxylated polymers would, of course, be expected to be repelled from the similarly charged planar faces. However, it has been found that crystals stabilized by very small quantities of an interlamellar complex forming substance can be distinguished by examination of thin sections of the swollen Na-montmorillonite gel under a polarizing microscope (Emerson, 1956c). In this way it has been possible to prove that the carboxylated polymers are not linked to the basal surfaces but must be linked to the edge faces.

The actual linkage depends on the proof by Schofield and Samson (1954) that the edge faces of kaolinite in addition to possessing a negative charge at high pH, due to dissociation of Si–OH groups, can become positively charged under acid conditions. From the similarity in crystal structure and from flocculation experiments, the edge faces of illite and montmorillonite must behave similarly. It is suggested that the polymers are linked by hydrogen bonds through the carboxyl groups to the oxygen and hydroxyls attached to aluminium atoms exposed at the edge faces, forming so-called peripheral complexes (Emerson, 1955b). Since the strength of the hydrogen bonds will depend on the readiness with which the edge faces and the dissociated carboxyl groups co-ordinate hydrogen ions, the efficiency of the polymers will depend both on the acidity and the pK of the carboxyl groups (Emerson, 1956a).

One important way in which the peripheral complexes may be distinguished from inter-lamellar complexes is that peripheral complexes may be dispersed by leaching with neutral pyrophosphate solution, while the latter are unaffected. The pyrophosphate ions displace the carboxyl groups. As a corollary, stable peripheral complexes could be equally well made with polyphosphates (Oplatka, 1954).

When the strength of crumbs from old grassland was measured after leaching with 0·1*M*-neutral pyrophosphate it was not much reduced, although an appreciable amount of organic matter was extracted (Bremner and Lees, 1955; Emerson, 1956b). It is concluded, therefore, that the fraction of the organic matter responsible for the increased crumb cohesion forms an inter-lamellar complex with the clay. After prolonged leaching with dilute alkali the strength of the grassland crumbs is reduced to that of Barnfield 80 crumbs. This contrasts with the stability of the PVA-stabilized crumbs, which are unaffected by alkali. However, inter-lamellar complexes made with gelatin slowly disperse if the pH is raised above the pK of the amino-groups, and by analogy it is suggested that the organic matter forms a polymeric inter-lamellar complex which depends partly for its strength on attraction between positively charged amino-groups and the negatively charged clay. The substance is thought to be polymeric because dispersion is slow and complexes formed with simple amino-acids disperse immediately the pH is raised sufficiently. If this is correct it could be an important source of nitrogen, which would be only slowly available, since it is known that the breakdown of substances is greatly reduced if sandwiched between clay particles (Ensminger and Gieseking, 1942).

Effect of Acidity on Crumb Strength

Reconsidering the first tests made with the sodium technique it was fortunate that the soil chosen, Barnfield, was buffered with free $CaCO_3$, for in acid soils increased stability may result from positive-edge to negative-face attraction. Crumbs taken from an acid arable field, Hoos, have been found to be much more stable than Barnfield 80 and, further, synthetic crumbs from the acid soil to which low-molecular-weight sodium alginate had been added were as unstable as the Barnfield soil (Emerson, 1956a). This makes it impossible at present in using the sodium technique to assess improvement in the wet strength of crumbs due to a ley unless the pH of the arable control is the same. It follows too that if liming improves soil structure it does not do so by increasing the wet strength of the crumbs. A possible way in which liming might be beneficial is if it maintains a sufficiently high concentration of Ca^{++} ions in the drainage water to ensure reflocculation of dispersed clay, provided at the same time the positive edges on the clay are neutralized by organic matter in solution. This is at present under investigation.

Until now it has been implied that if the clay fraction of the crumbs is stable, the crumbs themselves will be stable too. In other words, that clay–clay bonds are weaker than clay–sand bonds. Very little is known about the way clay is bonded to sand, but with our present techniques and knowledge of the forces exerted by clay particles, rapid progress should be possible.

Field Trials

Three groups of plots were sown in successive years to a variety of grasses and lucerne and with fallow strips as controls and left down for four years. Laboratory tests showed that the wet strength of the crumbs was appreciably increased by the grasses, particularly in the 0–2-inch layer. All the grasses were about equally effective, whereas lucerne had little effect. After ploughing up, heavy fertilizer dressings were given to minimize differences in the nutrient status of the plots, so that any difference in crop yield between the fallow and grass plots could be ascribed to structure. The first two blocks were sown in successive years to spring beans, winter wheat and spring barley. There was an increase in yield with the spring beans after grass, but unfortunately the yields were very low due to aphid attack. The only response with wheat and barley was an appreciable increase in yield of wheat after lucerne. This particular effect accords with results of ley–arable experiments elsewhere on the farm. This year on the third block, after ploughing up, the market-garden crops carrots and beet were sown. Immediately after germination, during prolonged dry weather, there was a spectacular increase in the rate of growth of carrots after grass, compared with the former lucerne and fallow plots. Later weather was particularly favourable for growth, and the final yield of carrots on the grass plots was not much higher. It appears, however, as though response to structure may be obtained from horticultural rather than agricultural crops.

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THE ELECTRONIC COMPUTER AT ROTHAMSTED

By

M. J. R. Healy

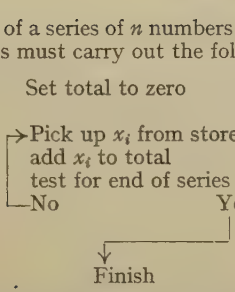
Since a certain amount of mystery still surrounds electronic computers—typified by the practice of referring to them as " Giant Brains "—it may be well to start by considering in outline just what these computers do and how they do it. In brief, they are capable merely of performing the simplest arithmetical operations, such as addition, subtraction and multiplication; their essential feature is that they carry out these operations extremely fast and completely automatically.

Any computer can be divided into a number of parts. To begin with, there will be some kind of input and output devices to allow for communication with the outside world. By comparison with the speed of carrying out arithmetical operations, these devices are usually rather slow, and, to enable the machine to work at full speed, the numbers it uses as data and as intermediate results will be held in some kind of store into and out of which they can be moved at " electronic " speeds. There will be an arithmetic unit or " function box " which, on being supplied with two numbers, will produce their sum, difference or product, and some kind of control mechanism that will call up the correct numbers successively from the store and set the arithmetic unit to perform the correct functions on them.

To enable a computer to carry out a given piece of arithmetic, the latter must be broken down into a sequence of additions, subtractions and multiplications. Together these form a sequence of instructions to the machine, which is called a programme and is also held in the store. Even a simple sum, however, requires a large number of instructions, and various devices are resorted to in order to get round this difficulty. The most important of these is the machine's rudimentary power of discrimination; ordinarily, the machine obeys the instructions in a fixed order, but at given points it is able to inspect some current result and to obey one or other of two alternative instructions according as this result is zero or not (or is negative or not). Thus we might construct a sequence of instructions to carry out one cycle of an iterative approximation scheme. At the end of the sequence the machine inspects the difference between the approximation just obtained and the one obtained in the previous cycle; if this difference is not zero (to the order of accuracy required) it must return to an earlier instruction and repeat the iterative cycle, while if the difference is zero it can proceed to a different stage of the calculations.

Many calculations can be carried out by means of a repeated cycle of instructions provided that a few of these instructions can be modified slightly at each passage through the cycle. Thus to

form the sum of a series of n numbers held in the store, the sequence of instructions must carry out the following operations :



At each passage through this cycle the " pick-up " instruction must refer to a different number in the store. An ingenious device enables the modification to be combined with a count which also provides the basis for the final discrimination. The numbers x_i are held in locations in the store which are numbered consecutively, and the " pick-up " order is so written as to refer to the first of these locations. Before it is actually obeyed, however, a count number i (starting at n) is automatically added to it in such a way as to make it refer to the ith location. At the end of each cycle, the count is reduced by one and then inspected to see whether it has reached zero; this provides the necessary discrimination, which enables the machine to leave this part of the computation and to proceed to the next.

Certain sequences of instructions are likely to be required in several different places during the course of a complete programme —for example, those for evaluating square-roots and for organizing the input and output of information. Such a sequence of instructions is known as a *sub-routine*; a sub-routine, once written, can be incorporated in any programme without the programmer having to investigate its detailed mode of operation. The usual technique is to supply the sub-routine, whenever it is entered, with a " link " instruction, which in the simplest case is merely the first instruction that is to be obeyed after the sub-routine has finished its task. This " link " is automatically stored by the sub-routine itself and ultimately referred to in order to get back into the main programme.

The N.R.D.C.–Elliott 401 Computer

The computer used in the Statistics Department has been described elsewhere (Lipton, 1955). In brief, it is a binary machine (working in the scale of 2 rather than the scale of 10 used in ordinary arithmetic) with a store containing 2,944 locations of 32 binary digits each (this is equivalent to between nine and ten decimals, and represents the accuracy to which normal arithmetic is carried out). The store is a magnetically coated disc rotating at over 4,500 r.p.m. The disc is divided into 23 tracks, each with 128 locations. Reading a number from the store takes 0·1 msecs. and this is also the time taken to carry out an addition or subtraction; multiplication takes 3·1 msecs. In addition to the main store, there are five registers, each of 32 binary digits capacity, which have immediate access— a number or instruction in the main store is only accessible once per

revolution of the disc, so that in an unlucky case up to 12·8 msecs. may be wasted in waiting for the required store-location to arrive at the reading–writing station. For this reason, consecutive instructions are not placed in adjacent locations in the store, but are spread out at the will of the programmer so that, as far as possible, each order becomes available for reading as soon as the previous order has been completed. To enable this to be done, each instruction specifies the location from which the next instruction is to be drawn.

Input to the machine is by 5-hole teleprinter punched tape. This is read by a tape-reader capable of operation at up to 200 rows per second, which is comparable with the computing speed of the machine. Very recently, a punched-card input has been added. Output is either to an electric typewriter operating at 8 characters per second or to a tape-punch, which is about three times as fast; output tape can be printed out on standard teleprinter equipment away from the machine.

The arithmetic and control units of the machine are built up of some 250 plug-in units of about a dozen different types. These carry out logical operations, and the arithmetical operations are built up by connections between the plates. This packaged construction is of immense help in the day-to-day maintenance of the machine and in the tracing of faults.

Programming and coding

The first step in organizing a piece of computation for the machine is to decide on the numerical methods to be employed. These may be quite different from those which would be adopted if the same problem was to be tackled on a desk machine. A good human computer is capable of taking advantage of peculiarities in the data, and of taking special action to retain accuracy at awkward places, but he is easily bored and inevitably subject to error in copying out intermediate results. The machine, on the other hand, will happily allow rounding off and cancellation errors to swamp its results, unless the programmer has taken steps to prevent this, but will carry out repetitive tasks rapidly and accurately.

The arithmetic process has next to be broken down into a number of logical steps, each of which can conveniently be considered in isolation. This is particularly important with a complex programme through which the machine may have to steer several different paths according to the precise nature of the data. Frequently, different parts of a large programme may perform practically identical operations on different intermediate results. These can conveniently be programmed as formal sub-routines.

The final stage consists in writing the actual instructions which enable the machine to perform the required operations. On the Rothamsted computer, each instruction specifies first a source of information, which may be the store or an immediate access register; next a function, which specifies the way in which the number from the source is to be combined with the contents of a special register called the accumulator; and next the destination to which the result of the previous instruction is to be sent. A further number is used to indicate discrimination or order modification as described earlier.

In addition, there is a timing number (in the form of a store address) which specifies the moment at which the order is to be obeyed; if the order contains a reference to the store, this timing address will specify the actual location required. Finally, the order contains the address in which the next instruction to be obeyed can be found. As an example, an order might read

1·52 6030 1·30

1·52, location 52 on track 1, is the address of the next order. Source 6 is the main store; the number from location 1·30 is to be added (function 0) into the accumulator, whose previous contents are to be sent to destination 3, one of the immediate access registers.

This " machine language ", though fairly complex, is sufficiently logical to be quickly mastered, and once the necessary arithmetic has been decided upon, the process of writing the appropriate orders is straightforward, if time-consuming. In practice, the logical section of the orders is written first, the addresses being filled in afterwards.

Statistical uses of the computer

The jobs handled by the computer fall into two main categories —routine tasks which, although individually simple, arise in sufficient volume to justify the writing of programmes, and more elaborate work which is too complex or time-consuming to be a practical proposition on desk machines.

In the first category the most important class of work is the analysis of the results of field experiments. These are readily handled by human computers—a fact which has contributed largely to the development of modern statistical methods in experimentation—but the volume of work involved has become considerable in recent years. Programmes are available for analysing randomized blocks (up to 126 plots), Latin squares (up to 10×10), randomized blocks with split plots (up to 128 sub-plots), 3^3 single-replicate factorial experiments and 2^n factorial experiments, which together account for some 80 per cent of all experiments reaching the department; other programmes are being developed. As an example of the speed of operation the actual analysis of a single variate takes about 15–30 seconds; input and output bring the total time up to about 2 minutes. Using these programmes, experiments involving a total of 2,500 analyses have been handled over the past two years.

A very important feature of these programmes is that they do all the work involved in an analysis. To begin with, the figures actually received from the field are very seldom those that are to be analysed; at least some conversion, say from lb./plot to cwt./acre, will be required, and often more elaborate initial computation will be called for. We use a general input routine for experimental designs which takes care of all this preliminary data-handling, places the required figures in the correct locations in the store and carries out certain checks to guard against punching errors. On the output side, the programmes are arranged to print their results in the customary form, leaving the minimum of clerical work to be done before the results can be dispatched to the experimenter.

Another source of routine work is probit analysis, which arises in insecticide research and other fields. Statistically, the problem is one of weighted regression, and the computations, though straightforward, are laborious and time-consuming. One of our programmes fits a single probit line to up to 16 observed points, printing out the equation to the probit line, the ED50 and its fiducial limits; natural mortality and heterogeneity in the data can be allowed for, and the same programme can without modification use the logit or angular transformations in place of probits. A further programme fits a bivariate probit regression, or probit plane. This useful technique has hitherto been neglected in practice because of the tedium of the computations involved.

Intermediate between the routine tasks and the large-scale computational problems are the programmes dealing with multiple regression. The first stage in regression calculations is the computation of sums of squares and products, and this can easily outweigh the more sophisticated calculations that follow it. We have several programmes for this purpose that can at will provide weighted or unweighted means, sums of squares and products, variances and covariances, standard deviations and correlation coefficients. These will shortly be adapted to punched-card input, since much multivariate material is most easily made available on punched cards.

The next step in multiple-regression calculations involves the inversion of a matrix and the calculation from the inverse of the regression coefficients and their standard errors. One programme will handle up to 24 variables, and inverts a 10×10 matrix in about 8 minutes. Another, given the sums of squares and products of up to 35 variables, enables the operator to select any one of these as a dependent variable and any selection of up to 9 others as independent variates. At each stage, the operator can add a new independent variate to his regression equation, replace the last independent variate added by a different one or delete one of the earlier independent variates. In each case, the machine will recalculate the regression and print out the residual mean square with its degrees of freedom and the regression coefficients with their standard errors.

Other programmes, which, though scarcely in routine use, are general in their application, have been devised to handle various matrix operations. As an example, one programme will evaluate all the latent roots and vectors of a symmetric matrix, an 8×8 matrix taking about 5 minutes. This problem arises in general discriminant analysis and has been used in a recent study by this technique of the teeth of fossil anthropoids.

A number of special problems involving heavy computations have been tackled on the computer, and some of these may be briefly mentioned. A large body of data from the Danish pig progeny testing stations is being analysed for Dr. J. W. B. King (Animal Breeding Research Organization, Edinburgh). Several different measurements are taken on each pig, and it is required to break down the observed variances and covariances into genetically meaningful components. The estimation of linkage values from human pedigree data is being undertaken for Dr. J. H. Renwick (Galton Laboratory).

It has been suggested that tsetse flies could be eradicated from an area by the release of large numbers of sterilized male flies. Practically nothing was known, however, about the numbers of flies which would be required, or about the length of time over which release should be continued. By setting up a mathematical model of the tsetse population and following it through many generations on the computer, both these points were investigated.

The feeding of dairy cattle is regulated on an empirical basis, and it is likely that the full efficiency of the cow is not being realized. K. L. Blaxter and H. Ruben (Hannah Dairy Research Institute) have approached this problem by setting up a rather elaborate mathematical model of the cow's metabolism. Fitting this model to observed data is an extremely arduous task, and is now being programmed for the computer.

There are many numerical problems which, although simple in themselves, are too time-consuming to be practical on desk machines. A typical example is the estimation of sampling errors for different patterns of sampling from completely known material. We have programmed this problem for the simple case when the sampling units form a linear sequence in space or time. The programme has been applied to data on human dietary constituents.

An obvious application of the computer is to the construction of mathematical tables, and several of the new tables in the fifth edition of *Statistical tables for biological, agricultural and medical research* were computed in this way. A large-scale project was the computation of tables of a generalized Beta distribution in collaboration with G. Foster (London School of Economics).

It may have been realized that the main difficulty in employing an electronic computer lies in the writing of programmes. The general outlines of the code of instructions for the 401 machine have been given above, and it will have been seen that programming is complicated by the "optimum access" feature—each instruction has to carry the address of the next instruction to be obeyed, and the relative placing of the instructions can have a large effect on the speed with which a programme will be carried out. In addition to this the relations to each other and to the location in which the instruction is stored of the two locations mentioned in each instruction (the timing address and the address of the next instruction) sometimes form part of the logical content of the instruction. For this reason, there are various conditions on the parities of the various locations that have to be borne in mind, and also certain delays which, if not imposed by the programmer, will cause the machine to "waste a revolution" or occasionally to perform the wrong operation. These conditions are straightforward but rather numerous, and form a potent source of errors when a programme is being written. To meet this problem, we have developed an automatic programming routine which enables this part of the programming load to be borne by the computer itself; the programmer uses a simplified coding to express the logical and arithmetic content of his instructions, and the routine fills the appropriate timing, at the same time indicating possible inconsistencies that it has detected in the simplified code. A register of occupied store locations is printed out, and an order tape punched ready to feed into the machine.

This routine has been found to produce programmes whose timing is as good as or better than the average human programmer and which contain far fewer errors when they are tested for the first time.

A field of application which we propose to develop in the immediate future is the application of the computer to sample-survey analysis. Apart from its speed of operation, there are several points at which the computer is expected to contribute. To begin with, any large batch of numerical data almost inevitably contains a few gross errors. These can have a disproportionate effect on the results, especially on estimates of error; yet their discovery and elimination is usually beyond the capacity of the unaided human investigator. We have made some progress using standard punched-card equipment, but much work remains to be done. A second task for which the computer is well suited is the preliminary computation of indices and other quantities on which the actual analysis will be carried out. Then, the data on one sampling unit may specify that x tons of some mixed fertilizer was applied to a field of y acres; what is required is the amounts of N, P and K applied, in cwt./acre. The full utilization of this stage will require machinery for punching from tape on to cards. Lastly, electronic computation should lead to improvements in the summary tables of results and to greater efficiency in the methods of collecting information, since the fact that some analytical technique requires elaborate numerical work need no longer be a barrier to its use.

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PUBLICATIONS

Physics Department

1. Emerson, W. W. (1956). Liquid crystals of montmorillonite. *Nature, Lond.* **178**, 1248.

2. Long, I. F. (1957). Instruments for use in micro-meteorology. *Quart. J. R. met. Soc.* **82**. (In the press.)

Descriptions are given of modifications and innovations in instrumentation for measuring—mainly by continuous recording—temperature, humidity and ventilation in and above crops. Details are provided for an arrangement that gives a direct measure of vapour-pressure gradient, and another that avoids spurious records from faulty contacts in a remote-reading anemometer.

3. McCulloch, J. S. G. & Penman, H. L. (1956). Heat flow in the soil. *Rep. 6th int. Congr. Soil Sci.* **B**, 275–280.

The usual analysis of the progress of the daily temperature wave into the soil is replaced by a treatment that takes into account the variation of diffusivity with depth. Applied to one set of data, the new analysis shows a 14-fold change of thermal diffusivity within 7·5 cm., and a similar range of thermal conductivity within 20 cm.

4. Monteith, J. L. (1956). The effect of grass-length on snow melting. *Weather*, **11**, 8–9.

5. Monteith, J. L. (1956). The heat balance of soil beneath crops. *Proc. Australia UNESCO Symposium on Arid Zone Climatology.*

Changes in the heat content of soil, estimated with flux plates, showed a day-time storage equal to about 20 per cent of net radiation (positive) and a night-time storage, depending on wind speed and soil moisture, frequently approaching 100 per cent net radiation (negative).

6. Penman, H. L. (1956). Evaporation from Lake Volta. In : *The Volta River Project*, **2**, App. III, 37–47. London : H.M. Stationery Office.

It is estimated that if a new Lake Volta is created in Ghana it will have a mean annual evaporation rate of 66 inches/year.

7. Penman, H. L. (1956). The movement and availability of soil water. *Soils & Fert.* **19**, 221–225.

Availability for transpiration and availability for growth are distinguished, and the former discussed in terms of potential gradient and conductivity against the background of the concepts of Veihmeyer, van Bavel and others.

8. Penman, H. L. (1956). Weather and water in the growth of grass. In : *The Growth of Leaves*, ed. F. L. Milthorpe, 170–177. London : Butterworth.

With water non-limiting, constant soil environment and prescribed nutrient status "constant" (in a limited sense of the word), the growth of grass (measured as dry matter in the leaves) appears to be closely proportional to the total energy supply available at the ground surface. As most of this "heat budget" is used in providing latent heat for transpiration, and the fraction so used is nearly constant, the growth is also closely proportional to the potential transpiration. Smaller deviations from exact proportionality could arise from uncertainty in the energy estimates : larger deviations, at establishment and in spring, could arise from root development at the expense of leaf development. Water appears to become limiting to growth at small values of the soil-moisture deficit, and the check occurs first on the crop

receiving smaller nitrogen dressings. The data available are too few to permit these statements being regarded as conclusions : they are merely clues to guide future thought and research.

9. Penman, H. L. (1957). Soil, plant and weather factors in irrigation. In : *Sprinkler Irrigation Manual.* Ringwood (Hants) : Wright Rain Ltd., pp. 34–44.

A general review of basic ideas and the results of recent irrigation experiments.

Chemistry Department

General Papers

10. Bremner, J. M. (1956). Some soil organic-matter problems. *Soils & Fert.* **19**, 115–123.

A review of current problems under the headings :

Effect of organic matter on soil structure.
Separation of organic matter ; metal–organic matter complexes.
The organic–nitrogen fraction.
The organic–phosphorus fraction.
Cation-exchange property.

11. Cooke, G. W. (1956). *The agricultural value of phosphate fertilizers which economize in the use of sulphuric acid.* [Report on Project No. 162 of the European Productivity Agency.] Paris : O.E.E.C. Pp. 90.

The results of field and pot experiments testing processed phosphate fertilizers which may be considered as alternatives to superphosphate are summarized. The work discussed was carried out in the member countries of O.E.E.C., which co-operated in this study. The fertilizers tested in the experiments were : dicalcium phosphate, nitrophosphates, phosphate fertilizers made by a variety of high-temperature processes, triple superphosphate, ammonium phosphates, calcium metaphosphate, ammoniated superphosphates and under-acidulated superphosphates. The residual effects of various types of phosphate fertilizers are also summarized. The availability of phosphate in relation to soil characteristics is discussed.

12. Cooke, G. W. (1956). Fertilizer placement. *Outl. Agric.* **1** no. 2, 43–51.

A summary of recent fertilizer placement research carried out in Britain. The value of placement for common crops is assessed, and the factors which affect the value of placement are discussed.

13. Cooke, G. W. (1956). Fertilizer placement for horticultural crops. *Comm. Grower*, 3168, 593–595.

14. Haines, W. B. (1956). A comparison of methods of soil analysis for phosphorus and potassium with field response in a group of experiments on sugar beet. *C.R. Assembl. Inst. int. Rech. betterav.* **19**. (In the press.)

15. Mattingly, G. E. G. (1956). Application of isotopes to soil and fertilizer research. *N.A.A.S. quart. Rev.* **33**, 93–101.

A short review of some of the applications of isotopes to soil and fertilizer research during the past ten years with special reference to field experiments.

16. Talibudeen, O. (1956). Isotopes in soil and fertilizer research. *Research, Lond.* **9**, 426–435.

The article deals with the application of tracer techniques to physical and chemical investigations of soils. The methods currently used in the analysis of soil constituents are reviewed, and the preparation of labelled compounds is described.

17. Widdowson, F. V. (1956). Improving the efficiency of fertilizer dressings. *Agric. Rev., Lond.* **1** no. 11, 20–26.

The advantages and disadvantages of various methods of applying fertilizer for peas, beans, horticultural and forage crops are described. A summary gives the best methods of application for a wide range of crops.

Research Papers

18. Arnold, P. W. (1956). Paper ionophoresis of inositol phosphates with a note on the acid hydrolysates of phytic acid. *Biochem. biophys. Acta*, **19**, 552–554.

A paper ionophoretic method for the fractionation of inositol phosphates is described. The method was used to follow quantitatively the hydrolysis of phytic acid at pH 3·0 and 120° C. Experimental results were compared with calculated figures based on a dephosphorylation involving six consecutive first order reactions with a single velocity constant.

19. Benzian, B. (1956). Nutrition problems in forest nurseries. Summary report for 1954. *Rep. For. Res. For. Comm. for* **1954/55**, 71–72.

20. Benzian, B. & Warren, R. G. (1956). Copper deficiency in Sitka spruce seedlings. *Nature, Lond.* **178**, 864–865.

For several years a symptom referred to as " needle tip-burn " has been observed in Sitka spruce seedlings grown on a highly leached sandy soil at Wareham, Dorset. The symptoms had been common in seedlings grown with inorganic fertilizers, but were absent from those grown on seedbeds treated with a compost made from bracken and hop-waste. In 1955 a foliar application of a copper sulphate solution with about 0·05 per cent copper greatly reduced " needle tip-burn ", it increased the height of the seedlings by nearly 50 per cent and the copper content by 40 per cent. The absence of tip-burn in seedlings grown on bracken and hop-waste compost has been ascribed to the high copper content of the hop-waste.

21. Bremner, J. M. (1956). Alkaline decomposition of β-hydroxy-α-amino acids. *Biochim. biophys. Acta*, **20**, 579–581.

The effect of hot alkali on serine, threonine, glucosaminic acid, β-hydroxyaspartic acid, β-hydroxyglutamic acid, β-hydroxyvaline, β-hydroxynorvaline, β-hydroxyleucine, β-hydroxynorleucine, β-phenylserine and β-p-hydroxyphenylserine was investigated by paper chromatographic techniques. It was found that all of these β-hydroxy-α-amino acids gave glycine when heated with alkali, that most also yielded the product $R{\cdot}CH_2{\cdot}CH(NH_2){\cdot}COOH$, and that some gave small amounts of other ninhydrin-reacting substances.

22. Bremner, J. M. (1957). Studies on soil humic acids. II. Observations on the estimation of free amino groups. Reactions of humic acid and lignin preparations with nitrous acid. *J. agric. Sci.* **48**, 352–360.

Free amino groups in humic acid preparations isolated from 0·5*M*-sodium hydroxide and 0·1*M*-sodium pyrophosphate (pH 7·0) extracts of various soils have been estimated by the nitrous acid method of Van Slyke (1929) and the fluorodinitrobenzene technique of Sanger (1945). The results obtained by the Van Slyke method using a reaction time of 15 minutes indicated that from 12 to 30 per cent of the total nitrogen in the preparations examined was in the form of free amino groups. No free amino groups could be detected by the fluorodinitrobenzene technique. It is shown that lignin interferes with the estimation of amino groups by the Van Slyke method, and it is suggested that lignin or lignin-derived material may be largely responsible for the high apparent amino-nitrogen values obtained with humic acid preparations by this method. The reaction of humic acid with nitrous acid resembles the reaction of lignin with nitrous acid in that it is accompanied by the fixation of nitrogen and the destruction of methoxyl groups. The reaction of lignin

with nitrous acid is similar in many respects to its reaction with nitric acid. Only about one-third of the nitrogen fixed by lignin in its reaction with nitrous acid is removed by prolonged hydrolysis with 6*N*-HCl, and most of this nitrogen is in the form of ammonia. A small amount of the nitrogen liberated by acid hydrolysis is in the form of hydroxylamine.

23. Bremner, J. M. & Shaw, K. (1957). The mineralization of some nitrogenous materials in soil. *J. Sci. Fd Agric.* (In the press.)

The mineralization in soil of various nitrogenous materials, including waste formalized casein from the plastics industry and products prepared from other waste materials such as lignin and sawdust, has been followed by determining the amounts of mineral nitrogen produced on incubation of the materials with soil under controlled conditions in the laboratory. Formalized casein and formalized hoof were found to decompose more slowly and uniformly than the unformalized materials. Deamination of casein had little effect on its rate of decomposition. Products prepared by treating lignin with nitric acid and with nitrous acid decomposed at similar rates and more rapidly than lignin–ammonia reaction products. Nitrated sawdust decomposed very slowly, and cellulose nitrate was highly resistant to decomposition.

24. Cooke, G. W. (1956). Field experiments on phosphate fertilizers. *J. agric. Sci.* **48**, 74–103.

The results of over 400 field experiments testing different kinds of phosphate fertilizers are summarized and are discussed with special reference to the reactions of the soils used. The classifications were : "very acid" soils, pH below 5·5; "acid soils", pH 5·6–6·5; neutral soils, pH over 6·5. All comparisons are made in terms of fertilizers supplying the same amounts of total phosphorus.

In war-time experiments Gafsa and Morocco rock phosphates were about two-thirds as efficient as superphosphate for swedes and turnips grown on very acid soils. In 1951–53 experiments on very acid and acid soils Gafsa phosphate was practically equivalent to superphosphate for swedes, but for potatoes it was as effective as only one-third as much phosphorus supplied as superphosphate; on neutral soils Gafsa phosphate was useless. For establishing grassland on acid soils Gafsa and Morocco phosphate were equivalent to about one-third as much phosphorus supplied as high-soluble basic slag. Rock phosphates were somewhat more effective for promoting growth of established grassland, but they remained inferior to high-soluble basic slags and to superphosphate. Curaçao rock phosphate was roughly equivalent to Gafsa phosphate for swedes and grass. Florida pebble phosphate was much less effective, and was judged unsuitable for direct application. Mixtures of rock phosphate with superphosphate were not more efficient than equivalent amounts of the separate components used correctly.

Silicophosphate was practically as effective as superphosphate for swedes grown on very acid and acid soils; it was less efficient on neutral soils. For potatoes silicophosphate was nearly as effective as superphosphate on very acid soils; it was much less efficient on acid and neutral soils. Silicophosphate was roughly equivalent to high-soluble basic slag for grassland.

Mixtures of superphosphate with lime, serpentine and low-grade basic slag were prepared, most of the water-soluble phosphorus being converted to insoluble forms. In experiments on swedes and potatoes these basic superphosphates were not superior to untreated superphosphate. For establishing grassland on very acid soils, the mixtures were slightly superior to ordinary superphosphate.

Dicalcium phosphate was practically equivalent to superphosphate for swedes on all groups of soils. For potatoes dicalcium phosphate was more efficient than superphosphate on very acid soils; on less acid and neutral soils it was inferior to superphosphate.

Nitrophosphates made by three different processes involving treatment of rock phosphate with nitric acid were tested in the field experiments. A product made by adding ammonium sulphate to the reaction mixture was most successful, perhaps because it contained an appreciable proportion of water-soluble phosphorus. Another product, made by using a mixture of nitric and sulphuric acids, was somewhat less effective; a third nitrophosphate, made by removing surplus calcium nitrate, was least successful. All the

nitrophosphates were less efficient than superphosphate for potatoes and for grassland; they were more effective on acid than on neutral soils. For swedes grown on acid soils all three nitrophosphates were equivalent to superphosphate.

A few experiments on swedes and grass grown on acid soils confirmed the use of the 2 per cent citric acid test for distinguishing between basic slags of differing agricultural values. Bessemer process basic slag was compared with superphosphate in many experiments. On average of all swede experiments Bessemer basic slag was as effective as only three-quarters as much phosphorus applied as superphosphate; for potatoes it was half as efficient as superphosphate. For both crops Bessemer slag was most effective on very acid soils and less useful on acid and neutral soils.

In a few experiments on potatoes and swedes triple superphosphate was roughly equivalent to ordinary superphosphate. Calcium metaphosphate was less effective than superphosphate for swedes.

Some experiments were continued to compare the residual effects of the tested phosphates. There was no evidence to suggest that superphosphate, silicophosphate, Bessemer basic slag and basic superphosphate mixtures differed in residual values for arable crops. Experiments on reseeded grassland indicated that highly-soluble phosphates have advantages for establishing the grass but that the less-soluble phosphates became more effective in later years. Slowly-acting nitrophosphates were relatively more effective in the second year than in the first year of experiments on grass.

Conventional solubility tests distinguish between processed phosphate fertilizers in powder form, but they may not be satisfactory for valuing granulated fertilizers containing phosphates insoluble in water.

None of the materials tested were as consistently satisfactory for potatoes and grass as equivalent amounts of superphosphate. Water-soluble phosphates are particularly effective on neutral soils. Swedes and allied crops grown on acid soils make full use of citric-soluble phosphates and also of certain rock phosphates.

25. Cooke, G. W. (1956). The value of rock phosphates for direct application. *Emp. J. exp. Agric.* **24**, 295–306.

In field experiments Gafsa, Curaçao and Morocco rock phosphates were more effective than Florida pebble phosphate. For swedes and turnips Gafsa phosphate was nearly equivalent to superphosphate on soils with pH values below 6·5; for potatoes and for grassland Gafsa phosphate was only one-third as effective as super, even on acid soils. In both pot and field experiments rock phosphates were almost useless on neutral and alkaline soils.

A number of different crops were grown in a pot experiment. Morocco phosphate was equivalent to superphosphate for radish; for swedes, rape and buckwheat it was about half as effective. For mustard, clover, ryegrass, timothy, wheat, barley, rye and lettuce Morocco phosphate was of little use.

Rock phosphates from a number of countries were tested in pot experiments on radish. Materials from Morocco, Algeria, Java, Egypt and Curaçao were a little less effective than that from Gafsa. Nauru Island phosphate was much less effective than Gafsa phosphate. Florida pebble phosphate, phosphatic chalk from Taplow (Berks) and phosphates from Nigeria, Christmas Island, Kola (U.S.S.R.), Uganda and Rhodesia were of very little use when applied to radishes grown in acid soils.

Field and pot experiments failed to provide any consistent evidence that rock phosphates should be ground more finely than is customary (80–90 per cent passing the 100-mesh B.S. Sieve).

Rock phosphates acted more slowly than superphosphate in pot experiments on radishes; their efficiencies tended to increase as the experiments were continued. The solubilities of rock phosphates were not appreciably increased by "composting" under acid conditions with wheat chaff in laboratory and pot experiments.

26. Cooke, G. W., Widdowson, F. V. & Wilcox, J. C. (1957). The value of mid-season top-dressings of nitrogen fertilizer for maincrop potatoes. *J. agric. Sci.* (In the press.)

Twenty-one field experiments were carried out from 1953 to 1955 on maincrop potatoes to compare dressings of nitrogen applied wholly to the seedbed

(as ammonium sulphate), with equivalent dressings applied partly to the seedbed (as ammonium sulphate) and partly as a top-dressing (of "Nitro-Chalk") just before the final ridges were set up.

There were consistent increases in yield from seedbed dressings of 0·5 and 1·0 cwt. N/acre. Seedbed dressings of 1·5 cwt. N/acre increased yields further in some experiments on light soils, but depressed yields at most heavy-land centres. In general, a dressing of 1·0 cwt. N/acre given to the seedbed was nearly sufficient for maximum yields.

The second increment of 0·5 cwt. N/acre increased yields at four-fifths of the centres when applied to the seedbed, but gave increases at only two-thirds of the centres when applied as a top-dressing. When the seedbed dressing was 1·0 cwt. N/acre a further seedbed dressing of 0·5 cwt. N gave increases in half of the experiments, but the same amount given as a top-dressing increased yields at only one-third of the centres. Splitting the dressing was inferior to applying it all to the seedbed in practically all experiments on medium and heavy soils. There was a slight advantage from splitting the dressing in about half of the experiments on light soils, but most of these gains were very small. On average, dressings of nitrogen applied wholly to the seedbed produced higher yields than equivalent amounts applied partly to the seedbed and partly as top-dressing.

In a subsidiary series of experiments top-dressings of "Nitro-Chalk" were applied to commercial crops which had been given normal manuring by the farmers at planting. On average of six experiments top-dressings gave only small increases in yield, none of the effects at individual centres was significant.

In both series of experiments top-dressings failed to prolong growth at centres where the crops were considered to have died prematurely. There is no justification for applying top-dressings of nitrogen fertilizer to potatoes which have received adequate amounts at planting. On the kinds of soil used for these experiments any loss of nitrogen (applied to the seedbed as ammonium sulphate) by leaching does not appear to be sufficient to reduce yields substantially.

27. Cooke, G. W., Bates, J. A. R. & Tinker, P. B. (1957). Investigations on soil nitrogen. I. The influence of nitrogen fertilizers and rainfall on soil nitrate concentrations. *J. Sci. Fd Agric.* (In the press.)

Changes in the concentrations of nitrate in soils taken from field experiments on cereals were followed for two months in spring 1955. At centres where nitrogen fertilizer increased yields of wheat and barley, soil nitrate at planting did not exceed 7 p.p.m.; in two experiments where the crops did not respond to fertilizer nitrogen there were 10 p.p.m. or more of nitrate present. Soil nitrate levels were markedly increased by additions of calcium nitrate and, to a lesser extent, by ammonium sulphate. Light rainfall which did not percolate deeply into the soil did not reduce nitrate concentrations seriously in the surface layers, but nitrate was reduced to very low levels at all centres by rain which percolated through 20 in. of soil.

28. Haines, W. B. & Benzian, B. (1956). Some manuring experiments on oil palm in Africa. *Emp. J. exp. Agric.* **24**, 137–160.

Results from ten manuring experiments on oil palm in Nigeria, Cameroons and the Belgian Congo are presented. Highly economic returns from the use of potassium were established in most cases, with smaller and more variable responses to phosphorus, and only uncertain or uneconomic ones to nitrogen. Calcium and magnesium limestone and magnesium sulphate were tested without sufficient response. Differences in response were shown between two soil types and between Lisombe and Deli palms. The differences could be related to the analysis of the soils for total P and K, although the conventional estimates of soluble or exchangeable fractions failed to show any clear relationship.

Possible interference from edge effects was taken into account in the design and recording of the experiments, and these effects are shown to develop in a way clearly due to poaching of fertilizers by palm roots crossing plot boundaries. This necessitated important corrections in the later years.

In addition to a definite annual yield cycle dependent on rain seasons, the

data revealed marked cycles in yield with three- to five-year periods, relatively large amplitudes and complicated phase relationships, which are probably influenced by the fertilizers. If this is not taken account of it can render the conventional interpretation of short-term results obscure and even misleading, and it produces unusual features in the analysis of variance.

29. Mattingly, G. E. G. (1957). Effects of radioactive phosphate fertilizers on yield and phosphorus uptake by ryegrass in pot experiments on calcareous soils from Rothamsted. *J. agric. Sci.* (In the press.)

Two pot experiments with ryegrass grown on calcareous soils taken from long-term experiments on Hoosfield, Rothamsted, are described. The effects of the method of application of ^{32}P-labelled phosphate, of the amount of ^{32}P tested and of the amount of phosphate applied are discussed.

Yield and total phosphorus uptake were slightly greater in the early stages of growth when superphosphate was applied as a powder than when an equal amount of monocalcium phosphate was applied in solution; this effect disappeared in later cuts of grass. Total phosphorus uptake was not significantly altered by the amounts of ^{32}P tested and yield was only significantly reduced at one sampling date in one experiment. The uptake of labelled (fertilizer) phosphorus decreased in both experiments at the higher rates of application of ^{32}P.

The addition of superphosphate or monocalcium phosphate increased the uptake of soil phosphorus on all soils on which there was a yield response to phosphate. On these soils the recovery of fertilizer phosphorus, estimated radiochemically, was less therefore than the increase in phosphorus uptake by the ryegrass.

The quantity of labile phosphate in the soils, which was shown to be almost independent of the amount of labelled phosphate added, increased by about one-third of the difference in total phosphate content on soils that had received heavy applications of superphosphate or farmyard manure over fifty years ago. The labile phosphate in soils that had recently received superphosphate in the field decreased in three years by more than the amount of phosphate taken up by the crop. In calcareous soils that had recently received rock phosphate, the labile phosphate was lower and did not decrease with time.

30. Mattingly, G. E. G. & Widdowson, F. V. (1956). The use of ^{32}P-labelled fertilizers to measure "superphosphate equivalents" of fertilizers in field and pot experiments. *Rep. 6th int. Congr. Soil Sci.* **B**, 461–470.

"Superphosphate equivalents" of phosphate fertilizers and fertilizer residues were determined in pot and field experiments from measurements of (*a*) yield response, (*b*) phosphate uptake and (*c*) the specific activity of the crops. Concordant results for "superphosphate equivalents" were obtained by the three methods with calcareous soils in pots, but high results were obtained with rock phosphates by the radiochemical method on acid soils. It is suggested that phosphate is taken up preferentially from phosphate-rich spots produced in such soils around particles of rock phosphate as they dissolve.

There was good agreement between results from all three methods in field experiments with dicalcium phosphate and rock phosphate, and for residues from superphosphate at an early stage of growth. At harvest, "superphosphate equivalents" determined from phosphate uptake and by the radiochemical method were much higher than from yield response, probably because of phosphorus uptake late in crop growth from fertilizer residues buried by ploughing.

31. Talibudeen, O. (1957). Isotopically exchangeable phosphorus in soils. Part II. Factors influencing the estimation of labile phosphorus. *J. Soil Sci.* (In the press.)

Methods used to determine isotopically-exchangeable phosphorus in soils are described and briefly analysed. The influence of soil : solution ratio, orthophosphate ions added with radio-phosphorus, the equilibrium pH and the removal of increasing amounts of phosphate from the soil are investigated.

A scheme is suggested for the subdivision of the total soil phosphate into four fractions on the basis of their abilities to exchange PO_4 ions with the phosphate in the soil solution. The relation between the labile pool of soil phosphate and this scheme is discussed.

32. Cano Ruiz, J. & Talibudeen, O. (1957). Surface properties of phosphate materials by isotopic exchange. Part I. Rock phosphates. *J. Sci. Fd Agric.* (In the press.)

Radioactive phosphorus was used to estimate the surface phosphate of apatite rock. Surface areas of these materials calculated from these estimates were smaller than those from gas-adsorption methods. Less than 2·5 per cent of the total phosphorus existed as surface phosphorus in the 100-mesh-size fraction of these materials.

33. Warren, R. G. (1956). N.P.K. residues from fertilizers and farmyard manure, in long-term experiments at Rothamsted. *Proc. Fertil. Soc.* **37**, 1–33.

The gain in soil nitrogen after farmyard manure had been applied annually for about a hundred years was between one-sixth and one-seventh of the total amount of nitrogen added in the manure. During the early years the gain was rapid and then continued to rise more slowly. Near the end of the period the nitrogen content of the farmyard manure plot on Broadbalk fell as a result of the fallows which were introduced into the cropping cycle. On the comparable plot on Hoosfield the nitrogen content of the soil rose but slightly during the last thirty years, indicating that the level, 0·27 per cent N, was close to the maximum for the rate and frequency of manuring in this experiment.

The organic matter residues from applications of farmyard manure given more than seventy-five years ago appear to be very stable. The residues provide only a small amount of mineral nitrogen for the barley crop.

In the years immediately after the year of application of farmyard manure the yields of potatoes, barley, ryegrass and wheat declined rapidly in the first residual year and then more slowly. For the wheat crop the fall can be ascribed to the shortage of available N, but the yields of potatoes, barley and ryegrass may also have been governed by the supplies of P and K or both.

P residues from superphosphate applied every fifth year over a period of twenty-five years gave increases in all four residual years in potatoes, barley and ryegrass. Wheat did not respond even in the year of application of the phosphate. For potatoes the increase in each of the last four residual years of the experiment was about half the increase obtained in the year of application of superphosphate : for barley the increase was one-third.

P residues from superphosphate and farmyard manure applied annually for a number of years last century increased the yield of barley grain by 7–10 cwt./acre fifty years after the last application. The P recovered in the crop each year from the residues was approximately 0·5 per cent of the total P applied as superphosphate or farmyard manure.

Five methods of soil analysis for P were used. Each method distinguished between soils that had received phosphate from those without added phosphate. The results by Olsen's method agreed more closely with the phosphorus content of the crops than did the citric acid, acetic acid and hydrochloric acid methods. Because the last three methods employed acid extractants which dissolved inactive mineral phosphate from the soils receiving this fertilizer, they did not distinguish between these soils and those that had received superphosphate and so failed to classify correctly the soils to which mineral phosphate had been applied. Olsen's method was successful in this respect.

Soils which had received potassium sulphate or farmyard manure for a number of years up to the end of the last century, but with none since, contained more readily soluble or exchangeable K than the untreated soils. For crops which contained similar quantities of P the amounts of K taken up from the K fertilizer and farmyard manure residues were related to the soil-K analyses.

34. Schofield, R. K. & Rees, D. H. (1956). Calculation of membrane pressure for a sol of spherical particles. *J. colloid Sci.* **11**, 617–622.

Electronic computation has been used to obtain the Poisson–Boltzmann

distribution of counter ions between an outer spherical surface, radius R_o, where the potential gradient is zero, and an inner concentric surface, radius R, representing a uniformly charged spherical particle. Here c_o is the concentration of the counter ions at the outer surface, and c_m is their mean concentration in the volume between the two surfaces. The results of the computations are given in a plot of c_o/c_m against $\ln \frac{R}{R_o}$. For given values of R and R_o, c_o at first increases linearly with the number of counter ions per particle, but ultimately approaches a limit. Values of the membrane potential, ϕ_o, are calculated from the equation $\phi_o = NkT(c_o - C)$. 1,000 for 1 per cent and 0·1 per cent sols of particles 10^{-6} cm. in radius.

Reviews

35. Bremner, J. M. (1956). "Modern Methods of Plant Analysis", edited by K. Paech & M. V. Tracey (4 volumes) [Review]. *Agriculture, Lond.* **63**, 299.

36. Widdowson, F. V. (1956). "Lucerne Investigations, 1944–53" (Grassland Research Institute memoir No. 1) [Review]. *Outl. Agric.* **1**, no. 3, 124.

Pedology Department

37. Bloomfield, C. (1956). The deflocculation of kaolinite by aqueous leaf extracts: the role of certain constituents of the extracts. *Rep. 6th int. Congr. Soil Sci.* **B**, 27–32.

A number of aqueous leaf extracts are very similar in their action on kaolinite; the compounds involved differ from species to species.

The activity of a Huon pine leaf extract appears to reside solely in its polysaccharide constituent, while Kauri and rimu barks appear to owe their deflocculating properties to the presence of polyphenols.

Aspen leaf extracts contain a polysaccharide and an acid of high molecular weight. Each of these is an active dispersing agent giving little or no reflocculation at high concentration. When acting together, an antagonistic effect operates, since a greater degree of reflocculation is produced.

38. Bloomfield, C. (1956). The solution-reduction of ferric oxide by aqueous leaf extracts; the role of certain constituents of the extracts. *Rep. 6th int. Congr. Soil Sci.* **B**, 427–432.

In the reaction between aqueous leaf extracts and ferric oxide, the greater part of the solution-reduction activity resides in the smaller molecular weight constituents of the extract. While removal of the constituents of higher molecular weight results in an intensification of the solution effect, addition of this fraction to an untreated extract leads to decreased solution of ferric oxide. It is apparent, therefore, that certain of the larger molecular weight components exert an inhibiting action in the solution-reduction process.

Kauri or rimu bark extracts exhibit a similar inhibiting action when added to their respective leaf extracts.

The solution-reduction process appears to be largely the result of the joint action of relatively simple acids and reducing compounds.

39. Bloomfield, C. (1956). The experimental production of podzolization. *Rep. 6th int. Congr. Soil Sci.* **E**, 21–23.

Periodic treatment of columns of ferruginous sand with dilute aqueous leaf extracts leads to discoloration of the ferric oxide. The ultimate appearance of the sand column is reminiscent of a podzol profile; the colour is not removed by washing with water. Most of the coloured substance is removed from the ferric oxide by dilute alkali, and the solution thus obtained is brown in colour and contains iron.

The substances responsible for the colour formation are chiefly of small molecular weight.

If, after treatment with the extracts, the columns are allowed to dry, B

horizons are formed at a short distance below the boundary between the dry and wet sand.

40. Brown, G., Dibley, G. C. & Farrow, R. (1956). An extrusion method for bonded powder specimens. *Clay Min. Bull.* **3**, 19–21.

A method of extruding powder specimens using a hypodermic syringe is described.

41. Brown, G. & Farrow, R. (1956). Introduction of glycerol into flake aggregates by vapour pressure. *Clay Min. Bull.* **3**, 44–45.

A vapour-pressure method of glycerol treatment of clays is described and its advantages over normal methods noted.

42. Brown, G. & Dibley, G. C. (1956). Moderately low angle measurements with a 9·0 cm. powder camera. *Clay Min. Bull.* **3**, 46–47.

A method of adapting a 9·0-cm. camera is described.

43. Brown, G. & Ollier, C. D. (1956). Collophane from the chalk. *Miner. Mag.* **31**, 339–343.

Samples of Upper and Middle Chalk from the Chilterns yielded fragments of fish scales, spines and bones, which consist of collophane. X-ray examination by powder methods showed that the material has an apatite-type structure with cell dimensions close to those previously reported for francolite. Examinations of single grains show that the optical anisotropy is due to preferred orientation of the *c*-axes of the crystallites, and this direction corresponds to the faster vibration direction. Such grains are found to be pseudo-uniaxial negative. Preferred orientation could not be detected in isotropic grains.

44. Greene-Kelly, R. (1956). The sorption of saturated organic compounds by montmorillonite. *Trans. Faraday Soc.* **52**, 1281–1286.

A number of new complexes of montmorillonite and compounds (some of biological importance) containing saturated chains and rings are reported. These complexes are compared with other similar complexes previously described and their structures discussed. The importance of single-bond rotation in intercalated chain molecules is emphasized.

45. Greene-Kelly, R. (1956). The swelling of organophilic montmorillonites in liquids. *J. Coll. Sci.* **11**, 77–79.

The crystalline swelling of amine-montmorillonites is shown to take place in certain liquids other than water. The relation between the steric requirements of the two kinds of intercalated molecules is discussed.

46. Greene-Kelly, R. (1956). Montmorillonite complexes with saturated ring compounds. *J. phys. Chem.* **60**, 808–809.

Two structural types of complex are found. The first in which the mean axis of the ring is parallel and the second perpendicular to the plane of the silicate sheets. The similarity to aromatic complexes is noted.

47. Nixon, H. L. & Weir, A. H. (1957). The morphology of the Unter-Rupsroth montmorillonite. *Miner. Mag.* (In the press.)

Electron micrographs of Na-saturated Unter-Rupsroth montmorillonite show that many of the individual flakes, which are probably 10 Å. thick, have straight edges meeting in 120° angles. This is evidence in support of the pseudohexagonal structure of montmorillonite. Similar pictures were obtained with Li-saturated clay, and with " Calgon " dispersed material. The usefulness of electron microscopy for the study of clay mineral morphology depends upon the efficiency of dispersion and the details of the mounting techniques rather than the nature of the exchange cation of the particular dispersing agent employed.

48. (Smithson, F.) with X-ray identifications by Brown, G. (1956). The habit of pyrite in some sedimentary rocks. *Miner. Mag.* **31**, 314–318.

Authigenic pyrite crystals or their pseudomorphs found in heavy residues from sedimentary rocks are cubes, octahedra or pyritohedra. Combinations of these forms are common; trapezohedron and rhombic dodecahedron faces are rare. The cube is most often recorded in the literature, but the octahedron is dominant in some districts and may be favoured by calcareous environment. X-ray tests have been applied for identification and goethite and haematite detected as alteration products.

49. Stephen, I., (Bellis, E.) & Muir, A. (1956). Gilgai phenomena in tropical black clays of Kenya. *J. Soil Sci.* **7**, 1–9.

An account is given of the occurrence of gilgai phenomena on tropical black earths in Kenya. Reference is made to examples from other parts of Africa. The Kenya soils are derived from intermediate lavas which weather to give montmorillonitic clays. The mineralogy of the sand fractions is described, and chemical and physical data given to illustrate the high swelling power of these heavy clay soils.

Soil Microbiology Department

50. Kleczkowska, J. (1957). A study of distribution and effects of bacteriophage of root nodule bacteria in the soil. *Canad. J. Microbiol.* (In the press.)

Bacteriophage to clover nodule bacteria can be found on roots and nodules of all naturally grown clover plants and also in the soil surrounding the roots, but not in the soil where there are no clover plants. Alternative hosts for the phage of clover bacteria are pea bacteria, and vice versa. The bacteria and the phage are heterogenous in the sense that only a proportion of strains of clover bacteria and of pea bacteria are susceptible to lysis by a given race of phage, and only a proportion of races of phage can lyse a given bacterial strain. There does not seem to be any necessary association between susceptibility of bacterial strains to lysis by a phage and any of such other features as antigenic structure and effectiveness in nitrogen fixation. There may be an association with avirulence, i.e., inability to infect the host plant.

The behaviour of phage–bacterial mixtures depends on the surrounding medium. The longevity of phage in soil, or in a soil-like medium such as the vermiculite mixture, is relatively short, and the effect of phage can be localized so that phage-susceptible bacteria and the phage can exist close to each other without any apparent interaction. However, as long as the phage is present phage-resistant bacterial mutants are also usually present. The phage-resistant mutants may also be mutants in other respects, such as effectiveness in nitrogen fixation. In the presence of weakened phage in such a system bacterial mutants that differ from the parent form in effectiveness but resemble it in being susceptible to the phage were found to occur.

51. Meiklejohn, J. (1956). Preliminary notes on numbers of nitrogen fixers on Broadbalk field. *Rep. 6th int. Congr. Soil Sci.* **C**, 243–248.

1. Counts of Azotobacter made on Broadbalk field in the summer and autumn of 1955 showed very small numbers in all cases.

2. On the fallow section of the unmanured plot 3, the numbers of Azotobacter rose during the summer and autumn; no such rise was observed in the fallow section of plot 10 (ammonium sulphate), where the numbers remained small, as they did in the sections that were carrying their fourth successive wheat crop.

3. On plots 5 (minerals only) and 7 (minerals and ammonium sulphate) there was an increase in numbers in the fallow section, not so much as in plot 3. In the cropped sections the Azotobacter numbers were higher than in the same sections of 3 and 10, but did not rise during the season.

4. Approximate counts of Clostridium show that the numbers are much higher than those of Azotobacter.

52. MEIKLEJOHN, J. (1957). Numbers of bacteria and actinomycetes in a Kenya soil. *J. Soil Sci.* **8**. (In the press.)

1. The estimates of numbers of bacteria and actinomycetes derived from plate counts made from soil samples taken at Muguga, Kenya, varied with the extent to which the soil was diluted. Low dilutions gave small, and high dilutions large, estimates.

2. The ratio between direct counts and plate counts on the same sample was wide at first, but became narrow as the drought of early 1953 was prolonged.

3. The percentage of actinomycete colonies on plates was less than 30 at first, but rose to over 90 when the drought was well established.

4. It is concluded that the drought-resistant part of the micro-flora in this surface soil is almost entirely composed of actinomycete spores.

53. NUTMAN, P. S. (1956). The influence of the legume in root-nodule symbiosis. A comparative study of host determinants and functions. *Biol. Rev.* **31**, 109–151.

54. NUTMAN, P. S. (1957). Symbiotic effectiveness in nodulated red clover. III. Further studies on inheritance of ineffectiveness in the host. *Heredity*. (In the press.)

A recessive host factor (*ie*) is described which effects the symbiosis between red clover and normally effective strains of nodule bacteria in such a way that no fixation of nitrogen occurs. With exceptionally effective strains of bacteria an effective response is found in nodules of some *ie* plants but not in others. Ineffective *ie* homozygotes bear variable numbers of nodules, some of which attain a large size. The ineffective response in *ie* plants is found to be influenced by other hereditary factors in the host which appear to promote effectiveness in a proportion only of the nodules formed on a root. Ineffectiveness in *ie* homozygotes differs from that produced by the factor i_1 (previously described) in (1) absence of a high degree of specificity with respect to bacterial strain, (2) types of nodulation and (3) mode of action of host modifying factors.

55. NUTMAN, P. S. (1957). Studies on the physiology of nodule formation. V. Further experiments on the stimulatory and inhibitory effects of root secretions. *Ann. Bot. Lond.* (In the press.)

The influence of root secretions on nodulation of clover and lucerne in agar culture is examined using a technique of preplanting. Root secretions are shown to have two effects : nodulation of the seedling is induced at an earlier stage (stimulation), but takes place at a reduced rate (inhibition). These effects do not depend upon the presence of the bacteria in the preplanting phase of an experiment. The species used differed both in production of and reaction to secretions giving these effects. As a donating plant lucerne is more active than clover, and selected early nodulating lines of clover are more active than late lines. Stimulation of lucerne is promoted by lower levels of secretion than clover, and early nodulating lines are less affected than late lines. The influence of secretions on nodulation rate is greater for lucerne than for clover at lower levels, and does not differ between early and late nodulating lines. In contrast to lucerne, inhibition of nodulation on clover is proportional to duration of the preplanting, suggesting that secretions accumulate during growth.

The hypothesis is put forward that the stimulating reaction represents an increase in the availability of the infective foci already present on the root and that the inhibiting reaction represents a reduction in the number of these foci.

56. PURCHASE, H. F. & NUTMAN, P. S. (1957). Studies on the physiology of nodule formation. VI. The influence of bacterial numbers in the rhizosphere on nodule initiation. *Ann. Bot. Lond.* (In the press.)

The direct examination of the relation between inoculum size and infection rate for the nodulation of a legume is difficult because of the rapid multiplication of the nodule bacteria in the rhizosphere. This has been overcome by

(1) using mixtures of normal (virulent) and mutant avirulent strains of clover nodule bacteria, the avirulent acting as a diluent of the virulent, and (2) by employing large original inocula to reduce multiplication. By these means the numbers of virulent clover bacteria were maintained during an experiment at approximately predetermined levels. When a strain of lucerne nodule bacteria was used as diluent the multiplication of clover-nodule bacteria was not suppressed.

Nodule number was found to approach the maximum asymptotically with bacterial density; very few bacteria (of the order of 10) were required to give rise to a single nodule only on a plant during an experiment, under conditions where the full nodulating capacity of a root is saturated by a total rhizosphere population of the order of 10^4 bacteria. This relationship supports the view that infection only takes place at discrete foci on the root.

A good fit of the experimental data was given by a compound Mitscherlich curve and by a combination of a normal and a modified Mitscherlich equation. This latter model takes into account the multiplication of sites of infection which occurs in the early seedling stage from foci not occupied at high dilution of virulent bacteria. Multiplication of this kind has also been demonstrated by delayed inoculation experiments.

In the preliminary experiments it was found that comparable rhizosphere stimulation of bacterial growth took place in sand culture, water culture and agar culture and with plants of diverse nodulating habit.

57. Steenson, T. I. & Walker, N. (1957). The pathway of breakdown of 2 : 4-dichloro- and 4-chloro-2-methyl-phenoxyacetic acid by bacteria. *J. gen. Microbiol.* **16**, 146.

The metabolism of 2 : 4-dichlorophenoxyacetic acid and 4-chloro-2-methylphenoxyacetic acid by a strain of *Flavobacterium peregrinum* and an *Achromobacter sp.*, respectively, has been studied. It was found that bacterial cells from young cultures were more active than those from older ones in oxidizing these substrates. Evidence is presented that adapted cells of these organisms dissimilate 2 : 4-dichlorophenoxyacetic acid through 2 : 4-dichlorophenol and 4-chlorocatechol and that 4-chloro-2-methyl-phenoxyacetic acid is dissimilated through 5-chloro-2-cresol. Bacteria adapted to 2 : 4-dichlorophenoxyacetic acid do not oxidize any of the other five possible isomers, but can oxidize 2 : 4-dibromo-, 4-bromo-2-chloro, 4-chloro- and, to a small extent, 2-chlorophenoxyacetic acid.

58. Stevenson, I. L. (1956). Antibiotic activity of actinomycetes in soil as demonstrated by direct observation techniques. *J. gen. Microbiol.* **15**, 372.

Direct observation techniques were used to determine the antibiotic effects of eight actinomycete species on *Helminthosporium sativum* in soil and *in vitro*. In actinomycete-inoculated sterilized soils the inhibition of germination of fungal spores corresponded with the degree of inhibition of the fungus produced by the same actinomycetes in Petri plate culture. The effects of the actinomycetes on the vegetative growth of *H. sativum* in soybean-supplemented soils varied with the individual actinomycetes and, with one exception, were identical with the effects caused by the actinomycete antibiotics *in vitro*. These hyphal changes in soil included : suspension of further mycelial development; lysis; characteristic morphological effects such as stunting, distortion, excessive branching and the formation of hyphal protuberances. Lysis of the fungal hyphae only occurred in the presence of soil, and was shown to be due to the combined effect of the antibiotic and some unidentified soil factor. Evidence was also obtained which demonstrated the ability of the actinomycetes to produce antibiotics in unsupplemented soils. Additional proof of antibiotic activity in soil was obtained by using the antibiotic actinomycin and strains of *Streptomyces antibioticus*, the organism responsible for its production. In Petri plate culture both crystalline actinomycin and the actinomycete produced a characteristic swelling, distortion and stunting of the vegetative growth of *Helminthosporium sativum*. When introduced into sterile soils, identical morphological changes were evidenced by the fungus in the presence of either the pure antibiotic or the actinomycetes.

59. Thornton, H. G. (1956). The ecology of micro-organisms in soil. (Leeuwenhoek Lecture.) *Proc. roy. Soc. Lond.* (*B*), **145**, 364–374.

60. Thornton, H. G. (1956). The development and present problems of soil microbiology. *J. Sci. Fd Agric.* **2**, 93–101.

61. Thornton, H. G. (1956). Soil organisms and root relationships. *Sci. Hort.* **12**.

Botany Department

General Papers

62. Thorne, G. N. (1957). Application of nutrients to crops as leaf sprays. *Agric. Rev., Lond.* **2**, 42–45.

63. Thurston, J. M. (1957). Towards the control of wild oats. *J. R. agric. Soc.* (In the press.)

64. Watson, D. J. (1956). Measurement of photosynthesis in field conditions. The physiological limitations of crop yield, and the possibilities of increasing it. *Landbouwk. Tijdschr., 's-Grav.* **68**, 581–594.

Text of two lectures given in 1953 in a course on Photosynthesis at the University of Wageningen.

65. Watson, D. J. (1956). Leaf growth in relation to crop yield. In : *The Growth of Leaves.* (Ed. F. L. Milthorpe, Proc. 3rd Easter School in Agric. Sci., Univ. Nottingham.) London : Butterworth. Pp. 178–191.

Research Papers

66. Owen, P. C. (1957). The effect of infection with tobacco etch virus on the rates of respiration and photosynthesis of tobacco leaves. *Ann. appl. Biol.* (In the press.)

Unlike tobacco mosaic virus, which increases the respiration of tobacco leaves within an hour of their being inoculated, a virulent strain of tobacco etch virus did not affect respiration rates until leaves showed external symptoms. The respiration rates of inoculated and systemically infected leaves with symptoms rose to 40 per cent above those of healthy leaves, three times the increase produced by tobacco mosaic virus. The increase in respiration rate occurred at all times of the year and was maintained through the life of the leaves.

Leaves infected with tobacco etch virus and showing symptoms had a rate of photosynthesis 20 per cent lower than that of healthy leaves.

67. Owen, P. C. & Watson, D. J. (1956). Effect on crop growth of rain after prolonged drought. *Nature, Lond.* **177**, 847.

After prolonged drought, rainfall in amounts very small compared with the soil moisture deficit and, therefore, with amounts used in orthodox irrigation practice, caused such large increases, both in leaf growth and in the rate of photosynthesis of unirrigated plants, that, temporarily, these plants grew faster than irrigated ones that had never been subjected to severe water stress.

68. Thorne, G. N. (1956). The effect of organophosphorus insecticidal sprays on the growth and phosphorus content of brussels sprouts. *Ann. appl. Biol.* **44**, 499–505.

No evidence was found that the insecticides schradan or demeton directly increase the growth of plants. The dry weight of brussels sprouts plants grown in soil supplying little or ample phosphorus was unaffected by spraying six times with schradan, demeton or sodium phosphate solutions supplying the

same amount of phosphorus as the insecticides, except that in one experiment schradan decreased the dry weight of plants grown with a high supply of phosphorus in the soil.

Phosphorus content was affected neither by demeton nor by the equivalent sodium phosphate sprays. In one experiment schradan and the equivalent sodium phosphate sprays increased the phosphorus content of plants grown in soil supplying little phosphorus, but did not affect that of plants with high phosphorus supply.

69. Thorne, G. N. (1957). Application of an April top-dressing of nitrogen to winter wheat in a spray with 2 : 4-dichlorophenoxyacetic acid. *J. agric. Sci.* **48**, 266–272.

Uptake of nitrogen by winter wheat from 0·5 cwt. N/acre applied in April as solid was about twice that from a similar quantity applied as a single spray at 30 gal./acre. Solid fertilizer increased yield slightly more than did spray. Urea and ammonium nitrate had the same effects with both solid and spray applications.

When 2 : 4-D was included in the spray or applied separately to plots receiving solid fertilizer, it decreased the amount of weed slightly and did not affect the yield of wheat. The response to nitrogen in dry weight of straw, including weeds, in one experiment, and of shoots in another experiment, was decreased slightly by 2 : 4-D when nitrogen was applied in spray but not when it was applied as solid fertilizer.

70. Warington, K. (1956). Investigations regarding the nature of the interaction between iron and molybdenum or vanadium in nutrient solutions with and without a growing plant. *Ann. appl. Biol.* **44**, 535–546.

Iron offset the toxicity of molybdenum or vanadium in nutrient solutions more effectively when it was supplied at the same time as the molybdenum or vanadium than when it was given separately in alternate 3-day periods.

Allowing nutrient solutions of pH 4·6 containing high concentrations of iron, with or without high vanadium, to stand 2–4 days before use reduced the iron content of the roots, and the vanadium content of both shoot and root, of peas. The presence of vanadium had little effect on iron uptake.

In parallel experiments with molybdenum, standing for 2–9 days reduced the iron content of the roots of soybean and peas, but the molybdenum content was unaffected or increased. High molybdenum greatly increased the iron in the root, but had little effect on that in the shoot.

Precipitation of iron in the nutrient solution was delayed by high concentrations of either ammonium or sodium molybdate if the initial pH was 4·6, but not if it was 6·6. Vanadium had no influence on the precipitation of iron at pH 4·6.

At least part of the compensating action of iron on molybdenum or vanadium toxicity appears to take place outside the plant.

71. Watson, D. J. & Wilson, J. H. (1956). An analysis of the effects of infection with leaf-roll virus on the growth and yield of potato plants, and of its interactions with nutrient supply and shading. *Ann. appl. Biol.* **44**, 390–409.

The decrease in total dry weight of potato plants caused by infection with leaf-roll virus was almost entirely at the expense of the tubers; the dry weight of the leaves and stems was increased, and that of roots and stolons only slightly decreased. The percentage loss of dry weight of the tubers was decreased by nitrogenous fertilizer, but was unaffected by phosphorus or potassium.

Infection greatly decreased net assimilation rate (NAR) between May and early July, but subsequently infected plants had a higher NAR than healthy plants. Infection also decreased leaf area per plant until early July, but it delayed senescence of the leaves, so that in late July and August infected plants had more leaf area than healthy plants. The more rapid senescence of healthy plants probably accounts for their lower NAR at this time. The mean decrease in NAR by infection was about 20 per cent, and this was the chief cause of the loss of yield, for the mean decrease in leaf area was only 4

per cent. The lower NAR of infected plants was mainly due to diminished photosynthetic efficiency of the older, rolled leaves. The effects of nitrogen, phosphorus and potassium on NAR, and their interactions with infection, were small and rarely significant.

At times when nitrogen, phosphorus or potassium increased leaf area they usually also increased the effect of infection, as this tended to reflect plant size. Infected plants had more leaves than healthy plants, because leaf production continued longer and more lateral branches developed.

Shading decreased NAR but increased leaf area; consequently it had no effect on yield. There were no interactions between shading and infection.

Biochemistry Department

General Papers

72. Pirie, N. W. (1956). The recognition, distribution and action of nucleic acids. *Proc. Chromosome Conf.*, ed. R. Prakken. Wageningen. Pp. 105–129.

73. Pirie, N. W. (1956). The use of higher plants for storing solar energy. *Trans. Conf. on Solar Energy*, ed. E. F. Carpenter. Tucson. (In the press.)

74. Pirie, N. W. (1956). Material in virus preparations not necessary for the manifestation of characteristic virus properties. In: *Ciba Foundation Symp. on the Nature of Viruses*, edited by G. E. W. Wolstenholme & E. C. P. Miller. London. Pp. 56–64.

75. Pirie, N. W. (1956). Nucleic acids and protein synthesis. (Chairman's Introduction to Biochem. Soc. Symp. No. 14.) Cambridge University Press. (In the press.)

76. Pirie, N. W. (1957). Chemical diversity and the origins of life. *Int. Union of Biochem., Symp. on the Origin of Life*, ed. A. I. Oparin. Moscow. (In the press.)

77. Pirie, N. W. (1957). Biochem ical engineering. *Research*, **10**, 29–34.

Research Papers

78. Byers, M., Fairclough, D. & Pirie, N. W. (1956). The large-scale production of leaf protein. *Biochem. J.* **63**, 33–34.

A description, for use when the Biochemical Society visited Rothamsted, of the equipment for making leaf protein. Figures are given illustrating the scale on which we work, the efficiency of extraction and the quality of the final product.

79. Clarke, A. J. & Mann, P. J. G. (1957). The oxidation of tryptamine to 3-indolylacetaldehyde by plant amine oxidase. *Biochem. J.* **65**, 763–774.

Plant amine oxidase catalyses the oxidation of tryptamine to 3-indolylacetaldehyde (IAc). This was established by the isolation of the 2 : 4-dinitrophenylhydrazone and dimedone derivatives of the IAc from the reaction mixtures. The oxidation of 5-hydroxytryptamine is also catalysed by the enzyme.

A method has been worked out for estimation of IAc based on its oxidation, with silver oxide, to 3-indolylacetic acid (IAA). The IAA so formed was estimated with Salkowski reagent.

Using this method, the effect of pH, substrate concentration and reaction time on the yield of IAc were investigated. The enzyme was rapidly inactivated at high tryptamine concentrations. With low tryptamine concentrations and short reaction times (15 minutes) yields of IAc of up to 90

per cent of theory were obtained at pH 7–8. The yield decreased with increase in reaction time, particularly with alkaline reaction mixtures. This was probably due, in part at least, to polymerization of the IAc.

It is suggested that the reaction forms a useful method of obtaining IAc.

Two of the secondary reactions which occur when crude preparations of the amine oxidase are used to catalyse the reaction were identified as peroxidase-catalysed oxidations of tryptamine and IAc.

80. KENTEN, R. H. & MANN, P. J. G. (1957). Manganese oxidation in the pea plant (*Pisum sativum* L.) grown under conditions of manganese toxicity. *Biochem. J.* **65**, 179–185.

Pea plants grown in water culture containing toxic concentrations of manganese sulphate accumulate compounds containing manganese of valency greater than two in the stems. The presence of these higher valency forms was demonstrated colorimetrically by the benzidine test and the amount present estimated spectrophotometrically as manganipyrophosphate and manometrically by the oxidation of hydrazine. It is suggested that the oxidation is due to peroxidase systems. Under toxic conditions of manganese supply the rate of oxidation of Mn^{2+} ions may exceed the rate of reduction of higher valency forms of manganese by plant metabolites, thus leading to the observed accumulation of manganese higher oxides. In other plants examined under similar conditions the accumulation of higher valency forms of manganese could not be demonstrated, possibly owing to the fact that in these plants they are reduced as fast as they are formed. It is suggested that the function of manganese as an essential element in plant nutrition depends, to some extent, on such valency change.

81. PIERPOINT, W. S. (1957). The phosphatase and metaphosphatase activities of pea extracts. *Biochem. J.* **65**, 67–76.

Pea extracts have a hexametaphosphatase activity, which is closely associated with an unspecific phosphatase. A variety of procedures, including protein precipitations, heat denaturation, absorption and ion-exchange chromatography, do not separate these activities or appreciably alter their ratio.

The phosphatase liberates orthophosphate from tripolyphosphate, trimetaphosphate, β-glycerophosphate, ADP and ATP, but not from tetrametaphosphate. It does not liberate phenol from diphenylphosphate.

The phosphatase is inhibited by fluoride and molybdate, but not by a variety of compounds that combine with SH– groups.

Ion-exchange chromatography of the phosphatase reveals two distinct enzymically active components. Each component can be separated from the other and rechromatographed as a single peak.

The two components are very similar in properties. They have the same pH optimum, are not affected by magnesium ions or chelating agents, have similar heat stabilities and differ only quantitatively in their specificities.

82. PIRIE, N. W. (1956). Unexploited technological possibilities of making food for man and animals. *Proc. Nutr. Soc.* **15**, 154–160.

A discussion of the factors that limit the use of leaves in human nutrition and of the techniques available for making edible protein concentrates from inedible leaves.

Some technical details of the equipment we use are given.

83. PIRIE, N. W. (1957). Macromolecular nucleoproteins from healthy tobacco leaves. *Biokhimiya*. (In the press.)

The microsome fraction made by ultracentrifuging extracts from healthy tobacco leaves contains ribonucleoprotein, ribonuclease, calcium and magnesium.

Particles with varying composition can be made by ultracentrifuging from fluids of different compositions, and this affects the stability of the particles and the rate at which they autolyse.

Plant virus preparations, made by gentle methods, contain similar particles.

Plant Pathology Department

Book

84. Broadbent, L. (1957). *Investigation of virus diseases of brassica crops.* (A.R.C. Report series No. 14.) Pp. ix, 94; 8 plates, 25 text figures. Cambridge University Press.

General Papers

85. Bawden, F. C. (1956). The transmission of plant viruses. (In: *Symposium on biological aspects of the transmission of disease.* Edinburgh: Oliver & Boyd.)

86. Bawden, F. C. (1956). The multiplication of plant viruses. (In: *The nature of viruses.* A Ciba Foundation symposium. London: Churchill.)

87. Bawden, F. C. (1956). Research on viruses and virus diseases. *J. R. agric. Soc.* **117**, 75–83.

88. Bawden, F. C. (1956). The impact of viruses on society. *Impact*, **7**, 85–101.

89. Bawden, F. C. (1956). Cure and prevention of virus diseases in plants. *World Crops*, **8**, 393–397.

90. Broadbent, L. (1956). Keeping seed from your own potatoes. *Grower*, **45**, 31–32.

91. Broadbent, L. (1956). Brassica virus diseases. *Agriculture, Lond.* **63**, 69–72.

92. Glynne, Mary D. (1957). Eyespot and take-all of wheat and barley. *Agric. Rev.* **2**, no. 10, 10–15.

93. Hull, R. (1956). Sugar Beet Yellows in Great Britain, 1955. *Plant Path.* **5**, 130.

94. Kassanis, B. (1956). Effects of changing temperature on plant virus diseases. *Advanc. Virus Res.* **4**, 221–241.

95. Kleczkowski, A. (1956). Effects of non-ionizing radiations on viruses. *Advanc. Virus Res.* **4**, 191–220.

96. Watson, M. A. (1957). The specificity of transmission of non-persistent viruses. *Proc. 10th int. Congr. Ent.* (In the press.)

Research Papers

97. Bawden, F. C. (1956). Reversible, host-induced, changes in a strain of tobacco mosaic virus. *Nature, Lond.* **177**, 302–304.

A strain of tobacco mosaic virus already unusual in that it can infect leguminous plants systemically is even more unusual in that its properties depend on the identity of the host plant in which it has been produced. From systemically infected solanaceous plants, it closely resembles the type strain of tobacco mosaic virus, whereas obtained from systemically infected leguminous plants it is less infective towards, and produces a different type of local lesion in, *Nicotiana glutinosa*, has a different antigenic constitution, different electrophoretic mobility and is more susceptible to inactivation by ultra-violet radiation.

98. Broadbent, L., Burt, P. E. & Heathcote, G. D. (1956). The control of potato virus diseases by insecticides. *Ann. appl. Biol.* **44**, 256–273.

Replicated trials in the years 1950, 1951, 1953 and 1954 showed that the spread of leaf-roll virus and virus Y in potato crops could be decreased by some insecticides. The crops were sprayed at intervals of 10 or 14 days, according to the stage of growth of the plants, with a tractor-mounted spraying machine at 100 gal. acre application. DDT emulsion, DDT suspension, endrin, schradan, "Mipafox", malathion, parathion and "Systox" prevented the spread of leaf-roll virus and decreased the spread of virus Y. Dieldrin and toxaphene were ineffective.

99. Buxton, E. W. (1956). Heterokaryosis and parasexual recombination in pathogenic strains of *Fusarium oxysporum*. *J. gen. Microbiol.* **15**, 133–139.

Mutants of *Fusarium oxysporum* f. *pisi* (cause of pea wilt), distinguished from the parent types by their different morphology, pathogenicity and nutritional requirements, were obtained by ultra-violet irradiation. Pairs of mutants with different nutritional requirements (auxotrophs) formed balanced heterokaryons on non-supplemented medium. Most of the auxotrophs were less pathogenic than the wild-types, whereas heterokaryons between the mutants were not.

Single conidia of a heterokaryon between an auxotroph from race 1 and one from race 2 of *Fusarium oxysporum* gave a small proportion (3 in 10^8) of colonies which were able to grow on non-supplemented medium. These three prototrophs were presumably diploid because vegetatively they gave new strains with various combinations of colour, nutritional requirements, actinomycete tolerance and pathogenicity.

The results indicate that, in fusaria, heterokaryosis plays a part in variation of virulence and that *Fusarium oxysporum*, which has no known sexual stage, has a system similar to the parasexual cycle described by Pontecorvo for certain other Fungi Imperfecti and that this permits the segregation and recombination of genetic factors.

100. Buxton, E. W. (1957). Some effects of pea root exudates on physiologic races of *Fusarium oxysporum* Fr. f. *pisi* (Lindf.) Snyder & Hansen. *Trans. Brit. mycol. Soc.* **40**. (In the press.)

Exudates from the roots of the pea cultivars, Onward, Alaska and Delwiche Commando, which differentiate between three physiologic races of *Fusarium oxysporum* f. *pisi*, affected spore germination in the three races differentially, depressing the germination of races they resisted more than of those to which they were susceptible. Exudates from young seedlings depressed germination more than did those from roots of older plants, and the activity of exudates increased temporarily when side roots were first formed.

When concentrated root exudates were contained in porcelain cylinders on agar sown with spores, zones of differential growth formed around the cylinders; when the exudate was from a cultivar resistant to the race whose spores were plated, the zone was one of growth inhibition, and when from a susceptible cultivar, it was one of growth stimulation. Notwithstanding this effect on spore germination, exudates from the different cultivars had no differential effect on the rate at which germ tubes or mycelium of the individual races grew.

Sections through roots of cultivars inoculated with a race they resist showed that the mycelium invaded only the outer cortex.

Plants susceptible to *F. oxysporum* wilt less when simultaneously infected with *F. solani*; extracts of the bases of pea plants infected with *F. solani* inhibited the germination of spores of *F. oxysporum*, whereas extracts from normal stem bases did not.

101. Harrison, B. D. (1956). The infectivity of extracts made from leaves at intervals after inoculation with viruses. *J. gen. Microbiol.* **15**, 210–220.

When leaves are macerated at intervals after being inoculated with plant viruses, the infectivity of the extracts obtained decreases with increasing

time until newly produced virus becomes detectable. Infectivity does not start to increase until approximately twice the time apparently needed for virus to multiply in the epidermis and spread from there to the mesophyll. Epidermal cells infected by inoculation seem to produce too few virus particles to be detected by infectivity tests, or else the first-formed particles are unstable *in vitro*.

No evidence was obtained, with Rothamsted tobacco necrosis virus (RTNV) in leaves of tobacco and French bean, that the initial decrease in infectivity occurs because of changes in virus particles that succeed in infecting and causing lesions. If such changes occur they are obscured by the inactivation of particles that do not multiply and cause lesions. Washing inoculated leaves removes 95 per cent of the inoculated virus, but only slightly decreases the numbers of infections, and adding "Celite" to the inoculum greatly increases the numbers of lesions without increasing the amount of virus retained by washed leaves. Neither washing nor adding "Celite" to the inoculum affects the rate at which the infectivity of successive extracts from inoculated leaves decreases. Infectivity continues to decrease after virus appears to have multiplied in and spread from the epidermis.

Cells of *Nicotiana glutinosa* that are infected by tobacco mosaic virus spreading from inoculated epidermal cells die only a few hours after the infectivity of leaf extracts starts to increase; few cells seem to become infected from virus produced in these secondarily infected cells and, at 20°, infectivity reaches a maximum in 2 days. Mesophyll cells of French bean leaves at 22° seem to synthesize new RTNV particles within 5 hours of becoming infected from the epidermis and to continue synthesizing for another 30 hours, when they probably contain about 10^6 virus particles/cell. Although the cells then die, the virus spreads to further cells and the infectivity of leaf extracts increases for at least five days.

102. Hirst, J. M. & Stedman, O. J. (1956). The effect of height of observation in forecasting potato blight by Beaumont's method. *Plant Path.* **5**, 135–140.

Records of wet- and dry-bulb temperature made with distant-reading mercury-in-steel thermographs were analysed to compare the occurrence of Beaumont periods at two heights. The sensitive elements of the instruments were placed either in standard louvred screens 4 feet above ground or in crops, beneath well-ventilated shelters, level with the crests of the potato ridges and mid-way between two. Computation of relative humidity was simplified by examining the records beneath a transparent plastic grid.

Observations from 1951 to 1955 show that in dry summers crop instruments allow relatively late outbreaks of blight to be predicted more accurately, whereas in wet summers Beaumont periods more often occur at both heights simultaneously. In dry seasons there tend to be more periods in screens than in crops, because crop instruments are near to bare soil which heats quickly when dry.

103. Kassanis, B. (1956). Serological relationship between potato paracrinkle virus, potato virus S and carnation latent virus. *J. gen. Microbiol.* **15**, 620–628.

Evidence is given that potato paracrinkle virus, potato virus S and carnation latent virus are serologically related and should be considered as related virus strains, although they differ considerably in their host range and pathogenicity, and only carnation latent virus is transmissible by aphids. It is suggested that the three have evolved from a common aphid-transmitted ancestor. In addition to the antigens the three have in common, each has many specific ones, and the two strains from potato are more closely related to one another than to the carnation virus.

No plant of the potato variety King Edward was found free from paracrinkle virus, and no Arran Victory plant free from virus S.

Minor variants of both paracrinkle virus and of virus S were detected: it is suggested that the variations in severity of symptoms developed when Arran Victory plants are grafted with King Edward scions reflect the various degrees to which different isolates interfere with each other's multiplication. Most isolates of virus S interfere only slightly with the multiplication of paracrinkle virus.

104. Kleczkowski, A. (1957). A preliminary study of tobacco mosaic virus by the gel diffusion precipitin tests. *J. gen. Microbiol.* **16**, 405–417.

A number of proteins can be separated from purified preparations of tobacco mosaic virus. They differ from each other antigenically, and all differ from the intact virus by not possessing all antigenic determinant groups possessed by the virus. Some of these proteins are easily detached from the virus by such mild treatments as placing it in a protein solution or in agar gel. These are antigenically identical with "*X*-protein" that remains in the supernatant fluid when the virus is sedimented by ultracentrifugation from sap of infected plants. More of these proteins are detached from the virus by placing it in boric acid–borax buffer at a pH about 8·7. When a more drastic treatment is applied, such as incubation at a pH about 10, when a proportion of the virus is disintegrated, still more of these proteins are released, but then some proteins antigenically different from those of "*X*-protein" are also released.

105. Nixon, H. L. (1956). An estimate of the number of tobacco mosaic virus particles in a single hair cell. *Virology*, **2**, 126–128.

The number of virus particles in a single hair cell from a systemically infected tobacco plant was estimated at 6×10^7 in a cell of about 250,000 μ^3, by counting virus particles in a section of known volume. Although inaccuracies are inseparable from such estimates, the figure is of the same order as that calculated from infectivity tests for the virus content of mesophyll cells in comparable leaves.

106. Nixon, H. L. & Fisher, H. L. (1957). An improved spray droplet technique for quantitative electron microscopy. *Brit. J. appl. Phys.* (In the press.)

Improvements are described to the spray droplet method of Backus and Williams (*J. appl. Phys.* **21**, 11 (1950)) for counting particles directly with the electron microscope. Decreasing the droplet size makes it possible to use much higher magnifications without sacrificing the ability to photograph each droplet trace entire on one frame, and droplets of the desired size are sorted and collected in a reproducible manner in a cascade impactor. The technique is also useful for studying the state of aggregation of a suspension.

Some factors affecting the accuracy of measurement of the polystyrene latex standard particles are discussed. Different methods yield different values, and there is at present no valid basis for selecting the best estimate.

107. Nixon, H. L. & Weir, A. H. (1957). The morphology of the Unter-Rupsroth Montmorillonite. *Miner. Mag.* (In the press.)

For summary see no. 47.

108. Salt, G. A. (1957). Effects of nitrogen applied at different dates, and of other cultural treatments on eyespot, take-all and yield of winter wheat. *J. agric. Sci.* **48**, 326–335.

A field experiment to test effects of cultural treatments on eyespot (*Cercosporella herpotrichoides* Fron.), lodging and yield of winter wheat, begun in 1952, was continued on the same site in 1953. In 1952 only eyespot and lodging were severe, but in 1953 take-all (*Ophiobolus graminis* Sacc.) and weeds were severe also.

Squareheads Master 13/4 and Cappelle, each sown at 1½ and 3 bushels/acre, were top-dressed at four different dates with ammonium sulphate at 0, 2 and 4 cwt. acre. Sulphuric acid (12½ per cent B.O.V. at 100 gal./acre) was sprayed on 4 of the 8 blocks of 10 plots in March to control eyespot.

Halving the seed rate decreased the percentage of severe eyespot from 63 to 52 per cent, decreased the area stunted by take-all from 36 to 14 per cent and increased yield by amounts ranging from 8·3 cwt. in nitrogen-deficient plots to 2·6 cwt. acre in plots well supplied with ammonium sulphate. The fertilizer applied to Squareheads Master at 0, 2 and 4 cwt./acre had little effect on the incidence of eyespot lesions at harvest, but increased the area lodged from 28 to 53 and 60 per cent respectively; it decreased the area stunted by

take-all from 47 to 19 and 10 per cent respectively, and increased yield from 13 to 17 and 18 cwt./acre. Cappelle did not lodge, and the fertilizer decreased take-all patches from 51 to 28 and 18 per cent respectively, and increased grain from 15 to 20 and 21 cwt./acre. The time when nitrogen was applied to either variety had no important effect on disease incidence or yield.

Sulphuric acid sprayed in 1953 on blocks unsprayed in 1952, and so having a higher initial infection of eyespot and weeds, decreased the area lodged and the area covered by weeds, but did not decrease the percentage of straws with eyespot below that in unsprayed plots.

109. Thresh, J. M. (1956). Some effects of tannic acid and of leaf extracts which contain tannins on the infectivity of tobacco mosaic and tobacco necrosis viruses. *Ann. appl. Biol.* **44**, 608–618.

The inhibition of infection by tobacco necrosis and tobacco mosaic viruses by tannic acid, and by extracts of raspberry and strawberry leaves, was associated with the precipitation of the viruses. Precipitation and inhibition were reversible, and infective virus was obtained from the precipitate formed between the viruses and tannins. Infectivity was fully restored by diluting mixtures of virus and tannin adequately and partially restored by adding alumina or nicotine sulphate.

Viruses and tannins are thought to form non-infective complexes, in which the virus and tannin components are held together by co-ordinate linkages or hydrogen bonds.

Macerating tobacco leaves infected with tobacco mosaic virus together with raspberry leaves greatly decreased the infectivity of the extracts; adding nicotine sulphate to the mixture of leaves before it was ground increased the infectivity, even though nicotine sulphate alone decreases the infectivity of tobacco mosaic virus. Even in the presence of nicotine sulphate, much of the virus was precipitated by substances from the raspberry leaves.

Extracts of roots of *Fragaria vesca* plants infected with a tobacco necrosis virus were more infective when made by macerating the roots with four times their weight of buffer at pH 8 than when made without buffer. Various methods are suggested for facilitating the transmission of viruses from plants that contain tannin.

110. Tinsley, T. W. & Richardson, D. E. (1956). Lucerne mosaic virus in potato—a new record for the British Isles. *Plant Path.* **5**, 133–134.

A strain of lucerne mosaic virus was found in apparently healthy potatoes growing in Northern Ireland. The virus was perpetuated in only a small percentage of tubers set by infected plants. French bean var. Prince is recommended as a test plant for identifying the virus.

111. Watson, M. A. (1956). The effect of different host plants of potato virus C in determining its transmission by aphids. *Ann. appl. Biol.* **44**, 599–607.

A stock of potato virus C derived from Edgecote Purple potatoes in 1945 was not then transmitted by aphids, although more than 2,000 aphids were used in conditions optimal for transmitting the serologically related potato virus Y. This stock of virus C has been propagated continuously since, by manual inoculation in a series of *Nicotiana glutinosa* and *N. tabacum*, and in 1955 it was transmitted by the aphid *Myzus persicae* (Sulz.); about one in twenty of the aphids transmitted it compared with one in two for potato virus Y.

Virus C derived from the Edgecote Purple potatoes in 1955 was not transmitted by aphids; both stocks of virus C produced only local lesions in Majestic potato leaves, and gave similar symptoms in tobacco.

When inoculated to Majestic potatoes and then returned to tobacco plants, potato virus C usually ceased to be aphid-transmitted and did not recover this property in any of the subsequent subcultures.

Transmission from stock by aphids did not isolate a strain of virus C which was any more readily transmitted by aphids; indeed, for the first two or three subcultures, aphids usually transmitted more readily from plants

inoculated manually. But the few isolates which remained aphid-transmissible after a second passage through potato were rather readily transmitted.

These results suggest that the ability of a virus to be aphid-transmitted is, at least in part, determined by the host plant in which it is multiplying, but the nature of the changes which determine this ability are unknown.

112. Watson, M. A. & Mulligan, T. (1957). Cereal yellow dwarf virus in Great Britain. *Plant Path.* (In the press.)

A virus which appears to be cereal yellow-dwarf virus has been isolated from cereals and grasses in Great Britain. In a preliminary field experiment, yields of barley were reduced by 37 per cent when plants were infected on 25 April and 18 per cent when plants were infected on 3 May.

113. Watson, M. A. & (Russell, G. E.) (1956). The value of glasshouse tests with seedlings in selecting plants tolerant to beet yellows virus. *Ann. appl. Biol.* **44**, 381–389.

Commercial strains of sugar beet, and breeders' lines of *Beta vulgaris* and *B. vulgaris* subsp. *maritima*, were exposed to infection with SBY and SBYN strains of beet yellows virus, using varying numbers of *Myzus persicae* as vectors, so as to cause a wide range of symptoms. The severity of the symptoms was assessed by scoring for superficial veinal necrosis ("etch"). All varieties of sugar beet tested were susceptible to infection, but the severity of the symptoms varied, particularly between the cultivated and wild beet types.

The scores for severity of symptoms made in the glasshouse were positively correlated with similar scores made in a field experiment using two cultivated and two wild beet types. The symptom scores were also positively correlated with losses in root and sugar yields caused by the virus.

Nematology Department

114. Doncaster, C. C. (1956). Some observations on the hatching responses of the cabbage-root eelworm, *Heterodera cruciferae* Franklin. *Ann. appl. Biol.* **44**, 283–291.

Larval emergence from cysts of *Heterodera cruciferae* was stimulated to a comparable degree by root diffusate from sprouts, swedes, rape-kale and white mustard. When mustard-root diffusate was added to leachings from the other species tested there was no apparent effect on larval emergence. For both sprouts and mustard-root diffusates, the hatching curves were similar in form. Estimates were obtained of the log activity values of leachings from the four species of plants and from soil.

115. Doncaster, C. C. (1957). Growth, invasion and root diffusate production in tomato and black nightshade inoculated with potato-root eelworm. *Nematologica*, **2**, 7–15.

Comparisons were made between the variations in growth, root diffusate production and extent of root invasion by the potato-root eelworm, *Heterodera rostochiensis* Woll. in tomato (*Lycopersicon esculentum* Mill.) and black nightshade (*Solanum nigrum* L.). Nematode inoculation more seriously affected root development in tomato, the more favourable of the two hosts, than it affected black nightshade. Although both host species were invaded, the nematodes reached maturity only in tomato; they failed to develop beyond the third larval stage in nightshade. During the first month of the experiment, tomato bore the greater density and the greater total number of nematodes in the roots. Thereafter there was a decline, but the numbers in the nightshade roots continued to increase. The effect of nematode inoculation on tomato-root diffusate output was to cause an apparently permanent reduction, while on nightshade it merely delayed the peak production of root diffusate.

116.* (Duddington, C. L.), Jones, F. G. W. & (Moriarty, F.) (1956). The effect of predacious fungus and organic matter upon the soil population of beet eelworm, *Heterodera schachtii* Schm. *Nematologica*, **1**, 344–348.

In microplots containing soil very heavily infected with beet eelworm, an experiment was undertaken to test the effect of very heavy dressings of fungal mycelium and organic matter upon the yield of beet and the final eelworm population. Both fungus (*Dactylaria thaumasia* Drechsler) and organic matter (bran) increased yield. Fungus had no effect upon the final cyst population, but organic matter caused a significant depression. Neither affected the final egg population.

117.* (Duddington, C. L.), Jones, F. G. W. & (Williams, T. D.) (1956). An experiment on the effect of a predacious fungus upon the soil population of potato-root eelworm, *Heterodera rostochiensis* Woll. *Nematologica*, **1**, 341–343.

A microplot experiment was made to test the effect of a predacious fungus (*Dactylaria thaumasia* Drechsler) and three types of organic material (leaf mould, compost and chopped cabbage) upon potato-root eelworm. The initial population of the eelworm was low, and the treatments were without effect upon the yield of potatoes or upon the final cyst and egg populations.

118. Fenwick, D. W. (1956). The breakdown of potato-root diffusate in soil. *Nematologica*, **1**, 290–302.

In experiments on the stability of potato-root diffusate in soil, 90 per cent of the active principle was lost in four days in a medium-grade loam. Comparative tests with soil components showed that breakdown was most rapid in sand and gravel and slowest in peat; clay gave an intermediate value. When repeated applications of diffusate were made to a loam, successive breakdown curves were each steeper than the previous, suggesting the presence of a micro-organism capable of utilizing the active principle as a substrate. This is confirmed by results with sterilized loam; newly sterilized loam is known to inhibit the action of root diffusate but, on standing for about six weeks, it loses this property: if diffusate be applied to this, then the breakdown is slower than in untreated soil. This, in conjunction with the result in peat, adds considerably to the theory of breakdown by micro-organisms.

119. Fenwick, D. W. (1956). The production of sterile viable larvae of the potato-root eelworm, *Heterodera rostochiensis*. *Nematologica*, **1**, 331–336.

Experiments are described on the production of sterile infective larvae of the potato-root eelworm. A variety of antiseptics gave sterile larvae, but the latter were not infective. Attempts to sterilize the eggs proved difficult because of a mucoid layer around them preventing the antiseptic reaching the egg wall. Treatment with 20-volume hydrogen peroxide for 5–8 hours proved effective, and such treated eggs hatched in root diffusate sterilized by filtration. This is the first stage in an attempt to set up infestations of this eelworm in sterile plant tissue cultures in order to investigate the mechanism of host–parasite specificity.

120. Fenwick, D. W. (1956). Red Ring disease of coconuts in Trinidad and Tobago. Report to Colonial Office. (Mimeographed; in production.)

This is a report on the author's visit to Trinidad to investigate Red Ring disease of coconuts caused by the nematode *Aphelenchoides cocophilus*. Little evidence was found that weevils were important vectors, although they were important pests in their own right. It was considered probable that the worm gained entry into the roots from the soil and penetrated into the base of the trunk, thereafter migrating upwards to form the characteristic cylinder of reddened tissue. Although the disease primarily affects young trees, a number

* Work carried out wholly or partly in the School of Agriculture, University of Cambridge.

of older trees were found suffering from it, but its importance in this respect is uncertain. There is some evidence that dropped nuts may be a factor in spreading the infection.

121. Forster, A. R. (1956). The development of *Heterodera rostochiensis* and *Meloidogyne incognita* in cross-grafted solanaceous plants with different susceptibilities. *Nematologica*, **1**, 283–289.

Two experiments were done to find out whether cross-grafting resistant and susceptible solanaceous plants would affect the development of nematode parasites within their roots. First, cross-grafted plants of susceptible tomato (*Lycopersicum esculentum* Mill.) and resistant black nightshade (*Solanum nigrum* L.) were inoculated with larvae of *Heterodera rostochiensis* Woll. In these plants the larvae developed normally irrespective of the scion, cysts being found on plants with a tomato root-system and none on those with a *S. nigrum* root-system. Secondly, larvae of *Meloidogyne incognita* (Kof. & White) Chitwood, 1949, were inoculated into soil around the roots of cross-grafted plants of susceptible tomato and resistant *Lycopersicum peruvianum* (L.) Mill. Very few female nematodes were found in the plants with *L. peruvianum* root-systems. In plants with tomato root-systems many females were found, but the total numbers and the percentage of those with eggs were significantly lower on those with *L. peruvianum* scions than on the self-grafted tomatoes. Thus, while there was apparently no transference of susceptibility from the tomato scion to the resistant *L. peruvianum* rootstock, a scion of *L. peruvianum* decreased the susceptibility of a tomato rootstock to attack by larvae of *M. incognita*.

122. Goodey, J. B. (1956). The susceptibility of potato varieties to infestation by the eelworms *Ditylenchus destructor* and *D. dipsaci*. *Ann. appl. Biol.* **44**, 16–24.

Twenty-five varieties of potato in common commercial cultivation were found to be susceptible to tuber attack by potato-derived populations of *Ditylenchus destructor* in experiments in fields and in pots. Stunting and leaf deformation may also be caused by the eelworms, but appear less consistently. A race of *D. destructor* from mushroom spawn had almost no effect on potatoes. Various races of *D. dipsaci* can reproduce in the shoot tissue of potato, sometimes causing damage. One population of this stem eelworm produced lesions on the tubers.

123. Goodey, J. B. (1956). Observations on species of the genus *Iotonchium* Cobb, 1920. *Nematologica*, **1**, 239–248.

Three new species of *Iotonchium* described by Meyl in 1954 have been critically examined and redescribed. Species of *Iotonchium* show precocious development in the males, and the heads of the males change in shape at the final moult from a radial symmetry to a bilateral one, becoming tri-lobed with dorso-ventral flattening.

124. Goodey, J. B. (1957). *Laboratory methods for work with plant and soil nematodes.* (3rd edition of T. Goodey, 1949 & 1951.) London : H.M.S.O.

In this third edition the original material has been rearranged and added to and some outmoded techniques omitted. There are sections on Collection and Extraction, Estimating *Heterodera* populations in the soil, Counting, Handling nematodes, Staining nematodes within plant tissues, Culture and Drawing nematodes. Two appendices give names of suppliers of apparatus and references to other techniques and equipment. There is an extensive bibliography and an index.

125.* Jones, F. G. W. (1956). Soil populations of beet eelworm in relation to cropping. II. Microplot and field plot results. *Ann. appl. Biol.* **44**, 25–56.

Experiments on specially constructed microplots were undertaken to

* Work carried out wholly or partly in the School of Agriculture, University of Cambridge.

overcome some of the difficulties associated with population studies using field plots. In these microplots Cruciferae caused greater increases in beet-eelworm populations than Chenopodiaceae when the initial population was low, and greater decreases when it was high. Non-hosts and inefficient hosts caused reductions of the same order as host plants in the same families.

When sugar beet was grown at varying initial populations, the final population tended to rise to a " ceiling " which varied with soil and season. The " ceiling " effect is also observed in the field and in pot tests, and may be used as a measure of the efficiency of different host plants or, if the same host plant is grown, as a measure of the effect of different soils and seasons. A linear relationship exists between the logarithm of the initial eelworm population and the yield of roots and tops.

Eelworm attack upon sugar beet renders the plants incapable of profiting from favourable growing conditions and reduces the size of the plants without affecting the percentage sugar content of the roots. Within certain limits, the final eelworm population is independent of yield or plant density. Cruciferae are far less susceptible to injury by root invasion than the cultivated varieties of *Beta vulgaris*.

It is suggested that host efficiency in raising and supporting eelworm populations and susceptibility to injury are distinct and independent attributes of host plants. Decay of populations in land under fallow or non-host crops in non-host families was approximately 20, 40 and 50 per cent per annum for cysts, cysts with contents and eggs respectively, and appears to be largely independent of initial population level. The average egg content of cysts with contents falls from 177 eggs/cyst in the first winter after the cultivation of a host crop to 131, 118 and 114 in the second, third and fourth respectively. The *in vitro* hatch from beet-eelworm cysts is affected by previous cropping. Low hatches are sometimes obtained in the winter and spring after the cultivation of host crops, especially where there has been considerable increase. A period of maturation appears to be necessary before eggs are fully sensitive to hatching stimuli.

The implications of the microplot results are briefly discussed. Population increase appears to be limited by intraspecific competition rather than by specific enemies. The development and decline of infestations follow a course similar to that in other pests, but, because of lack of mobility, the time factor is greatly extended. The differential effects of soil, season and host crop render set rotations ineffective as a measure of control once land has become generally infested. At this stage a system of advice based on soil sampling is described.

125*a*.* Jones, F. G. W. (1956). Soil population studies using microplots. *Nematologica*, **1**, 109–110.

A summary of the foregoing paper given at the Third International Nematology Symposium.

126.* Jones, F. G. W. (& Moriarty, F.) (1956). Further observations on the effects of peas, beans and vetch upon soil population levels of pea-root eelworm, *Heterodera göttingiana* Liebscher. *Nematologica*, **1**, 268–273.

In microplot and garden-plot experiments peas caused marked rises in cysts and egg populations of pea-root eelworm. Vetch doubled the number of cysts but gave only a small increase in eggs. Field bean also nearly doubled the number of cysts but barely maintained the egg population. Longpod and Windsor beans caused relatively small increases in cyst numbers and reduced the egg populations. Despite the high initial egg populations of some plots, no symptoms of pea " sickness " appeared in 1955, probably because of the cool, moist weather during the growing period and possibly also because of the nitrogenous fertilizer applied to the plots.

127.* Jones, F. G. W. (& Moriarty, F.) (1956). A preliminary experiment on the effect of various cereals on the soil population

* Work carried out wholly or partly in the School of Agriculture, University of Cambridge.

of cereal-root eelworm, *Heterodera major* O. Schmidt. *Nematologica*, **1**, 326–329.

In an experiment with microplots, oats and barley caused greater increases in cereal-root eelworm populations than did wheat. The highest population followed barley, variety Herta. A slight decline followed barley, variety Kron, and wheat, variety Bersee, both of which gave final populations significantly lower than most other cereal varieties tested. Because of the previous uniform treatment of the plots, population changes were adequately measured by cyst counts which gave greater precision than the egg counts.

128.* Jones, F. G. W. (1957). Sugar-beet pests. *Bull. Minist. Agric., Lond.* no. 162. (In the press.)

An illustrated bulletin for farmers giving the life history, biology and control of the more important insect and nematode pests of sugar beet and allied crops and incorporating the results of recent research.

129.* Wallace, H. R. (1956). Soil aeration and the emergence of larvae from cysts of the beet eelworm *Heterodera schachtii* Schmidt. *Ann. appl. Biol.* **44**, 57–64.

Moisture content, pore size, depth and oxygen consumption in the soil, which influence soil aeration, have been studied in relation to larval emergence from cysts of the beet eelworm. Experiments show that the rate of larval emergence increases with aeration. In studies of larval emergence in the field, emphasis should be laid on soil structure rather than on a mechanical analysis. Those factors associated with good soil tilth favour high rates of larval emergence.

130.* Wallace, H. R. (1956). The emergence of larvae from cysts of the beet eelworm, *Heterodera schachtii* Schmidt, in aqueous solutions of organic and inorganic substances. *Ann. appl. Biol.* **44**, 274–282.

The rate of larval emergence from cysts of the beet eelworm in a variety of aqueous solutions containing organic and inorganic substances is significantly higher than the emergence rate in water. It is suggested that differences between larval emergence rates in monoamino-monocarboxylic amino-acids may be related to the lipid solubility of these substances and their ability to penetrate the egg membranes. The larval emergence rate in fructose, glucose, sucrose and maltose was significantly higher than that in water, but in raffinose, arabinose and xylose the rate of emergence was no higher than in water. A high rate of larval emergence occurred in sodium chloride, potassium chloride and mercuric chloride, but not in magnesium chloride or calcium chloride. Experiments with several other organic solutions are described. There is an optimum concentration for larval emergence in beet diffusate. The osmotic pressure of the diffusate when maximum emergence occurred was 0·48 atm. Measurements of shrinkage of unhatched larvae in various concentrations of urea, sodium chloride and sucrose showed that decreasing rates of emergence at higher concentrations may be due to changes in the unhatched larvae brought about by an osmotic effect. High concentrations of beet diffusate may have a similar effect.

131.* Wallace, H. R. (1956). Migration of nematodes. *Nature, Lond.* **177**, 287–288.

An apparatus is described for the study of the relation between the hydrostatic pressure-deficiency and the migration of *Ditylenchus dipsaci* in sand particles 200–400 μ and water. With an increase in the pressure-deficiency from 5 to 40 cm. of water the migration of the eelworm rose correspondingly; when the increase was greater than 40 cm. of water migration declined. At the pressure-deficiency for maximum mobility of 40 cm. of water in the sand particles about 25 per cent of the pore space is occupied by air. Experiments in progress suggest a similar relationship between the distribution of water in sand and the migration of *Heterodera schachtii*.

* Work carried out wholly or partly in the School of Agriculture, University of Cambridge.

132.* Wallace, H. R. (1956). The effect of soil structure on the emergence of larvae from cysts of the beet eelworm. *Nematologica*, **1**, 145–146.

The influence of pore-size, moisture content and aeration on the emergence of larvae from cysts of the beet eelworm are discussed. A soil in good tilth which favours plant growth also favours larval emergence. In studies on larval emergence in the soil the influence of soil structure as distinct from soil type may be important.

133.* Wallace, H. R. (1956). The seasonal emergence of larvae from cysts of the beet eelworm, *Heterodera schachtii* Schmidt. *Nematologica*, **1**, 227–238.

Field experiments in 1954 and 1955 showed that there was a high rate of larval emergence from cysts of the beet eelworm during April and May, followed by a low emergence rate from June to September. It is shown that low soil moisture content was probably the chief factor inhibiting emergence during the summer months. Larval emergence probably does not occur in soil where the pressure deficiency exceeds 150 cm. of water. Recording of pressure deficiency in four soil types during 1955 showed that from June to September the pressure deficiency was mostly above this level. A comparison of larval emergence from cysts within and between soil crumbs was made. At least 50 per cent of the cyst population occurred within crumbs, but the rate of larval emergence from these cysts was very low. It is suggested that when counts of cysts in soil are made a dispersing agent such as " Calgon " should be used to release cysts enclosed in soil crumbs.

134. Welch, H. E. (1956). *Studies on a number of nematodes parasitic in insects.* Ph.D. Thesis, University of London.

This thesis gives the results of work on species of *Aphelenchoides* parasitic in *Drosophila* spp. and a critical review of the family *Mermithidae*.

Insecticides Department

General

135. Last, F. T. (1956). Use of Antibiotics against plant diseases. *Nature, Lond.* **178**, 1330–1331.

136. Lord, K. A. (1956). Insect rearing and methods of testing insecticides. *Proc. biochem. Soc.* **63**, 35–36.

137. Potter, C. (1956). Resistance of insects to insecticides: the effect of age and stage of development and nutrition. *Chem. & Ind.* (no. 42), 1178–1181.

138. Potter, C. (1956). Resistance of insects to insecticides. *Nature, Lond.* **177**, 355–357.

139. Potter, C., Elliott, M. & Ward, J. (1956). Pyrethrins: a British viewpoint. *Pyrethrum Post*, **4**, 15.

140. Way, M. J. (1956). A full crop of beans. *Fmr & Stkbreed.* 29 May, 57.

141. Way, M. J., Glynne Jones, D. G. & Johnson, C. G. (1956). Work in England on the effect of insecticides and other chemicals used in plant protection on beneficial insects and insect populations. *Proc. 5th tech. Mtg int. Union Prot. Nature.* Copenhagen, 1954.

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* Work carried out wholly or partly in the School of Agriculture, University of Cambridge,

Research

142. Broadbent, L., Burt, P. E. & Heathcote, G. D. (1956). The control of potato virus diseases by insecticides. *Ann. appl. Biol.* **44**, 256–273.

For summary see no. 98.

143. Last, F. T. & Hamley, R. E. (1956). A local-lesion technique for measuring the infectivity of conidia of *Botrytis fabae* Sardiña. *Ann. appl. Biol.* **44**, 410–418.

Discrete lesions developed when conidial suspension of *Botrytis fabae* Sardiña were rubbed with the forefinger on leaves of broad bean plants (*Vicia faba* L.) subsequently kept in a water-saturated atmosphere. The numbers of lesions which developed were directly proportional to the concentration of inoculum. At equal concentrations, conidia from young cultures produced more lesions than conidia from old cultures.

Variation in lesion numbers between plants within a pot always considerably exceeded the variation between opposite half-leaflets of a leaf, as did variation between pots and between leaves of old, but not of young plants.

As the standard error of the number of lesions developing per half-leaflet (x) increases as the mean increases, the values of x need to be transformed before being statistically analysed. A suitable transformation is

$$z = \log_{10}\tfrac{1}{2}[x + c + \sqrt{(x^2 + 2cx)}], \text{ where } c = 20.$$

144. Lord, K. A. & Solly, S. R. B. (1956). The rate of disappearance of paraoxon from two strains of houseflies. *Chem. & Ind.* (no. 45), 1352–1353.

A normal strain of housefly and one twice as resistant to poisoning by paraoxon were examined for differences in the *in vitro* inhibition of enzymes which hydrolysed acetyl choline, triacetin and phenylacetate respectively. No differences could be detected. *In vitro* tests failed to demonstrate the hydrolysis of paraoxon by housefly tissue extracts.

Tests on whole flies treated with paraoxon showed a rapid disappearance of the poison at apparently the same rate in both strains of flies. The disappearance of paraoxon was followed both by the inhibition of added cholinesterase and chromatographic methods.

145. Tattersfield, F. & Kerridge, J. (1957). The effect of repeated spraying of insects on their resistance to insecticides. IV. The effect of diet and of population factors upon resistance. *Ann. appl. Biol.* (In the press.)

(1) The effect of diet and population factors upon the resistance to DDT of a strain of adult *Drosophila melanogaster* have been investigated. Resistance was lowered by the omission of protein from the insects' diet, and raised by both bakers' yeast and casein (water-soluble and vitamin-free) added to an agar medium containing sugar solution (molasses, honey, dextrose). When yeast, both alive and dead, was added to the medium, the insects completed their reproductive cycle, whereas casein had little or no effect on their development, although the larvae were slightly larger than with sugar solution alone. When sugar alone and sugar plus casein were used, the larvae, from eggs laid by adults reared on a yeasted medium, remained undersized until they died before or during pupation. Yeast emulsion heated to 100° C. and added to an agar–sugar medium enabled the life cycle to be completed, but fewer adults were developed than with live bakers' yeast, and the resistance to DDT was less.

(2) Wild yeasts, such as *Sporobolomyces roseus* and N.C.Y.C. 365 (*Saccharomyces cerevisiae*—var. *ellipsoideus*), were effective food substitutes for bakers' yeast, and the resistance to DDT of adults fed on a medium on which *S. roseus* were grown, was somewhat higher than on that containing *S. cerevisiae*.

(3) Changing the adults to fresh media every few days induced higher resistance. The nearer the administration of fresh food to the date of spraying the higher the resistance, and this may have ameliorated the effect of ageing, particularly if the sexes were separated each day.

(4) The separation of the sexes appeared to affect the males deleteriously, but the presence of larvae in the medium slightly increased the resistance of both sexes to DDT, possibly because the larvae broke up the surface of the medium.

(5) Population density of the larvae had a significant effect on the life cycle of *D. melanogaster*; the weight of the adult declining with density, and the length of the life cycle increased whether the adults or the larvae were overcrowded.

With the adults, lowering the population pressure of the females increased resistance to DDT until a relatively constant level was reached. With the males, the resistance measured at the L.C. 50 was higher if females were absent from the population and, except at the highest densities, appeared to be independent of numbers.

The effect of increased population density of the larvae was to increase resistance to DDT of the resulting adults. This might be correlated to some extent with decline in size, but only within certain limits, and the indications were that a more intense selection had taken place with increasing density.

Entomology Department

Book

146. Barnes, H. F. (1956). *Gall midges of economic importance.* Vol. VII : *Gall Midges of Cereal Crops.* London : Crosby Lockwood and Son Ltd.

General Papers

147. Barnes, H. F. (1956). Gall midges as pests of farm crops. *Agriculture, Lond.* **63**, 265–267 and 336–339.

148. Johnson, C. G. (1956). Changing views on aphid dispersal. *N.A.A.S. quart. Rev.* **32**, 62–67.

149. Johnson, C. G. (1956). Ecological aspects of aphid flight and dispersal. *Rep. Rothamst. exp. Sta. for* **1955**, 191–201.

150. Mellanby, K. (1956). Acclimatization in insects. *Sci. News, Harmondsworth*, **40**, 71–77.

Research Papers

151. Banks, C. J. (1956). The distributions of coccinellid egg batches and larvae in relation to numbers of *Aphis fabae* Scop. on *Vicia faba*. *Bull. ent. Res.* **47**, 47–56.

152. Banks, C. J. (1956). Observations on the behaviour and mortality in Coccinellidae before dispersal from the egg shells. *Proc. R. ent. Soc. Lond.* (*A*), **31**, 56–60.

153. Banks, C. J. (1956). A second record of a tachinid parasite bred from one of the Coccinellinae (Col., Coccinellidae). *Ent. mon. Mag.* **92**, 188.

154. Carter, C. I. (1956). Massing of *Tetranychus tiliarum* (Hermann) (Acarina, Tetranychidae) on the trunks of Lime Trees. *Ent. mon. Mag.* **92**, 73–74.

155. Dobson, R. M. (1956). A new species of *Carpophilus* Stephen (Col. Nitidulidae) associated with stored products. *Ent. mon. Mag.* **92**, 41–42.

A description of a new species of the *C. dimidiatus* (F.) complex emanating from the U.S.A., Brazil and Morocco.

156. Dobson, R. M. (1956). A note on the relative abundance of flea beetles (*Phyllotreta* Stephens and *Psylliodes* Berthold) on different cruciferous crops. *J. hort. Sci.* **31**, 291–294.

Differences in compositions and densities of flea-beetle population of different adjacent cruciferous crops are noted and discussed.

157. Dobson, R. M. & Lofty, J. R. (1956). A simple cage for comparing small insects during experimental exposure to fumigants, etc. *Ent. mon. Mag.* **92**, 157–158.

Small cages made of washers and fine metallic gauze are described.

158. Dobson, R. M. & Lofty, J. R. (1956). Observations on the effects of BHC (Hexachlorocyclohexane) on the soil fauna of arable land. *Rep. 6th int. Congr. Soil Sci.* **C**, 203–205.

Some effect on the soil fauna of applying BHC to the soil of a four-course rotation are discussed.

159. Dobson, R. M. & (Satchell, J. E.) (1956). *Eophila oculata* at Verulamium; a Roman earthworm population? *Nature, Lond.* **177**, 796–797.

During archaeological excavations living worms were found amongst layers of blackened organic material in a filled-in Roman ditch between 8 and 15 feet below ground level. The circumstances suggested that they may have been breeding there since the ditch was filled in during Roman times.

160. French, R. A. (1955). Migration records 1954. *Entomologist*, **88**, 123–130.

161. French, R. A. (1956). Migration records 1955. *Entomologist*, **89**, 139–145, 174–180.

162. French, R. A. (1956). Insect migration in 1955. *Countryside*, **17**, 462–465.

163. Johnson, C. G. (1956). Distribution and dispersal of aphids in the air. *Mitt. biol. BundesAnst. Berl.* **85**, 22–23.

164. Johnson, C. G., Southwood, T. R. E. & Entwistle, H. (1957). A new method of extracting arthropods and molluscs from grassland and herbage with a suction apparatus. *Bull. ent. Res.* (In the press.)

165. Mellanby, K. (1956). Mosquito populations at Ibadan in Nigeria. *Bull. ent. Res.* **47**, 125–136.

For over 2 years 70 earthenware pots filled with water were exposed in different types of environment. Every 5 days the water was strained, all mosquito larvae being removed, counted and identified. Data showing fluctuations in numbers of *Anopheles gambiae, Aedes aegypti, Lutzia tigripes* and various Culicines are given. The limitations of this and other sampling techniques are discussed.

166. Mellanby, K. & French, R. A. (1957). Some effects of changes of temperature and of the physical nature of the environment on the activity and behaviour of mealworm larvae (*Tenebrio molitor*). *Brit. J. Anim. Behav.* **5**. (In the press.)

167. Milne, D. L. (1956). Gall midges affecting seed production in clover. *Ann. appl. Biol.* **44**, 669–670.

168. Murphy, P. W. (1956). A modified funnel method for extracting soil meiofauna. *Rep. 6th int. Congr. Soil Sci.* **C**, 255–262.

Details of the split-funnel extractor, a modified funnel method for extracting soil fauna are given, together with results of an experiment to test the

apparatus, and the effect of sample treatment on extraction efficiency. With heathland samples best results are obtained when litter and raw humus are extracted separately, the latter in thin layers (1·3–1·9 cm.), in an undisturbed condition. There is little difference between room temperature and a heated funnel (air temperature 30–35° C.) for extraction of litter, although with raw humus the latter is more effective.

Both desiccation and temperature appear to be important factors in the process. Treatment results indicate the importance of a temperature stimulus in the early stages of extraction, and that good recovery will depend upon striking a balance between a temperature which, although not providing a too rapid drying rate, is sufficient to cause a definite negatively thermotactic response.

169. Murphy, P. W. (1956). Soil faunal investigations. *Rep. For. Res., Lond. for* **1954/55**, 83–84.

170. Murphy, P. W. (1956). Soil-fauna systematics. " Die Nordost-Alpen im Spiegel ihrer Landtierwelt ", by H. Franz [Review]. *Soils & Fert.* **19**, 4–6.

171. Raw, F. (1956). The abundance and distribution of Protura in grassland. *J. Anim. Ecol.* **25**, 15–21.

Using a flotation method, 1,425 Protura were extracted from 90 soil samples taken from selected Park Grass plots at Rothamsted in October 1950. Of these 85 per cent were identified as *Proturentomon minimum* (Gisin), the rest as a species of Eosentomon, probably *E. armatum* Stack.

The Protura were aggregated in such a way that the majority of individual sample counts fell within the range one-half to twice the geometric mean of the population. The degree of aggregation appeared to be independent of the population density. Their distribution was associated with conditions induced by liming. Both species were correlated with exchangeable calcium. *P. minimum* was also correlated with soil pH and the abundance of *Helicotrichon, Trisetum* and *Dactylis* spp. The significance of their aggregation and distribution is briefly discussed.

172. Stokes, B. M. (1956). A chemotactic response in wheat bulb fly larvae. *Nature, Lond.* **178**, 801.

A method of growing young wheat plants in petri dishes of sodium alginate jelly for use in testing the larval reactions of wheat bulb fly is described.

In a series of experiments, cubes of this jelly, taken without including any part of the wheat plant, were placed on damp filter-paper in a closed petri dish together with similar cubes taken from a dish in which no wheat had been grown. Newly hatched wheat bulb fly larvae were placed centrally and moved into the " wheat-jelly " cubes, but they failed to show any reaction towards the non " wheat-jelly " cubes. It is possible that a response to some such stimuli may enable the larvae to find their host plants, and the paper outlines further lines of investigation.

173. Stokes, B. M. (1957). Observations and experiments on the Hessian Fly (*Mayetiola destructor* Say). *Ann. appl. Biol.* **45**, 122–132.

Experiments showed that a stem midge collected at Rothamsted on *Agropyrum repens* and similar midges on wheat, barley and rye were of the same species, *Mayetiola destructor* Say. There were three main flights per year, with some overlapping of the generations. In experiments, *Aegilops ovata, Triticum compactum, T. dicoccoides, T. durum, T. spelta* and *T. turgidum* were successfully used as host plants besides wheat, barley, rye and couch grass. Individual female midges when moved from plant to plant gave rise to families on the different host plants; similarly, succeeding generations of midges were able to breed on various host plants other than those from which they themselves were reared. Oviposition also took place on plants on which larvae failed to establish themselves. In experiments, wheat was a more favourable host plant for developing larvae than couch grass, both when the parent midges had themselves been collected from couch grass and when

laboratory stocks with predecessors from a number of host plants were used as parents. More midges were reared from young plants than from mature ones.

Unisexual families occurred in about half the experiments. The following parasites were bred: *Trichacis didas* Walker, *Eupteromalus ? hemipterus* Walker, *Platygaster* sp., *Chrysocharis* sp. and *Tetrastichus* sp.

174. Williams, C. B., Common, I. F. B., French, R. A., Muspratt, V. M. & Williams, M. C. (1957). Observations on the migration of insects in the Pyrenees in the autumn of 1953. *Trans. R. ent. Soc. Lond.* (In the press.)

Observations were made on extensive movements to the south of many species of Lepidoptera and Diptera at several localities in the Pyrenees; there was little evidence of a similar movement of Odonata.

Bee Department

Research Papers

175. Bailey, L. (1956). Aetiology of European Foul Brood; a disease of the larval honeybee. *Nature, Lond.* **178**, 1130 only.

The method of culture of *Streptococcus pluton* is described, and a summary is given of experiments showing that this disease appears to be caused by the simultaneous growth of *S. pluton* and *Bacterium eurydice*.

176. Bailey, L. (1956). A device for collecting samples of bees. *Bee World*, **37**, 70–71.

A description is given of a simple hand-operated suction device which enables the operator to collect up to 200 live bees from a hive in 15–30 seconds.

177. Bailey, L. & Carlisle, E. (1956). Tests with acaricides on *Acarapis woodi* (Rennie). *Bee World*, **37**, 85–94.

Full details are given of laboratory and field trials with various acaricides including the newer di-(*p*-chloro-phenyl) derivatives. The use of the latter, applied as a smoke, during warm weather has been found very effective; much benefit is achieved by a single treatment, and elimination of infection is possible by two treatments.

178. Butler, C. G. & (Haigh, J. C.) (1956). A note on the use of honey-bees as pollinating agents in cages. *J. hort. Sci.* **31**, 295–297.

Equipment is described which makes it possible to use a colony of honey-bees to pollinate plants in a screen-cage in the field without contamination from unwanted pollen and without heavy loss of bees. The hive is sited outside the cage, and the bees can be directed either into the cage or into the open air by adjustment of a simple slide and without opening the hive.

179. Butler, C. G., Free, J. B. & Simpson, J. (1956). Some problems of red clover pollination. *Ann. appl. Biol.* **44**, 664–669.

The abilities of bumblebees and honeybees to pollinate red clover are discussed, and the various methods that have been employed in attempts to increase the numbers of these insects visiting red clover fields are reviewed. Owing to the difficulties and uncertainty of success of the methods so far devised, it is suggested that efforts should be made to determine whether insufficient pollination is, in Britain, an important cause of poor red clover seed yields.

180. Butler, C. G. & Simpson, J. (1956). The introduction of virgin and mated queens, directly and in a simple cage. *Bee World*, **37**, 105–114.

It was found to be much easier to introduce a queen to a colony from which a similar queen (virgin, mated, etc.) had just been removed than to one

from which a dissimilar queen had been taken. When a large-mesh cage was used to introduce mated tested queens, without attendants or food, to colonies which had just been dequeened, at least 90 per cent success could be obtained when the queens removed were mated and laying, and at least 80 per cent when they were virgin. The successes achieved with various types of queens and colonies, at different times of year, both by direct and cage introduction, are discussed.

181. Free, J. B. (1955). The collection of food by bumblebees. *Insectes soc.* **2**, 303–311.

Data are given on the time factors involved in the collection of food by bumblebees. The uptake of sugar syrup by worker bumblebees was investigated in order to obtain information about the collection of nectar by foragers under natural conditions.

182. Free, J. B. (1956). A study of the stimuli which release the food begging and offering responses of worker honeybees. *Brit. J. Anim. Behav.* **4**, 94–101.

Excised heads alone are sufficient to release the food begging and offering responses of worker honeybees. Bees beg from the lowest part of a head irrespective of its orientation. The antennae on a head provide a contact stimulus with a releasing function, and their effect can be simulated by the use of "model" antennae. The scent of a head is an important stimulus, and heads possess a greater releasing value if taken from bees belonging to the same colony as that of the offering and begging bees. Whereas movement appears to play no part in releasing the begging response, it is significant in releasing the offering response. Bees whose antennae had been removed were able to offer food but not to beg for it. Both food begging and offering are innate reactions which improve in precision with age independent of conditioning.

Statistics Department

General Papers

183. Boyd, D. A. (1956). Fertilizers can be used to better effect. *Times Agric. Rev.* Spring 1956, p. 5.

184. Boyd, D. A. (1956). Sugar-beet manuring: a re-examination of the experimental data. *Brit. Sugar Beet Rev.* **25**, 19–22.

185. (Tanner, J. M.) & Healy, M. J. R. (1956). The genetics of human morphological characters. *Advanc. Sci.* **13**, 192–194.

Research Papers

186. Boyd, D. A. (1956). The effect of potash on crop yield. *Potassium Symposium*, 1956. (In the press.)

The paper brings together the results of a large number of annual experiments carried out in Great Britain on the effect of potash on crop yield. Expressed as a percentage of the mean yield, the largest responses were obtained from potatoes, and somewhat smaller responses from root crops and beans; in general, the effect of potash on cereals was small. Responses in Scotland were approximately double those obtained in England.

The average effects of potash obtained from a four-course rotation experiment at Saxmundham and of six-course rotation experiments at Rothamsted and Woburn are also discussed. At Saxmundham, where the fertilizer treatments are repeated annually on the same plots, beans and clover were more sensitive to shortage of potash than wheat, mangolds or barley. At Rothamsted and Woburn, where substantial maintenance dressings of potash were applied during the rotation, only potatoes at Rothamsted gave substantial responses.

The interactions of potash with farmyard manure and with other fertilizers are briefly discussed.

R

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187. Boyd, D. A., Garner, H. V. & Haines, W. B. (1957). The fertilizer requirements of sugar beet. *J. agric. Sci.* (In the press.)

The paper describes the results of over 300 factorial experiments carried out in each factory area in the years 1934–49 for the Sugarbeet Research and Education Committee of the Ministry of Agriculture as a result of co-operation between Rothamsted workers and the agriculturists and fieldmen attached to the beet factories. All the experiments tested the effects of levels of nitrogen, phosphate and potash, and rather more than half tested the effect of salt also.

Except on fen soils, nitrogen gave substantial responses in all factory areas, especially in the presence of high levels of potash or salt. Large variations in response from season to season were closely associated with the rainfall of the preceding winter months, responses being greater after wet winters than dry ones.

In spite of some selection of sites in favour of greater responses, the average net returns from phosphate were relatively small.

The effect of potash was closely linked with the amount of nitrogen applied; in the presence of nitrogen, dressings well above the level of 1·2 cwt. K_2O acre tested in the experiments are likely to give a useful net return. Soils derived from the Chalky Boulder Clay seem to be exceptional in showing no response. Apart from this, there were only small variations in responses to nitrogen and potash between factory areas. The application of 5 cwt. salt gave substantial responses in almost all parts of the country, whether or not potash was also applied; on the other hand, responses to potash were usually small when salt was also applied.

Whilst there was a general relationship between soil analysis for phosphate and potash (citric acid method) and crop response, adjustments to the optimal dressings according to soil analysis were not of sufficient reliability to be of much practical value.

188. Boyd, D. A. (1957). The manuring of sugar beet. *J. agric. Sci.* (In the press.)

Information on how growers actually manure their crops is available from the Survey of Fertilizer Practice, carried out by the Provincial Soil Chemists of the National Agricultural Advisory Service, in collaboration with Rothamsted. These data indicate that, taking into account the nutrients in farmyard manure, the average amounts of nitrogen and potash applied are not far from the optimal amounts suggested by experiment, whilst phosphate dressings are on the average at least double requirements. This may be due in part to the fact that few compounds are available with a low ratio of phosphate to other nutrients.

189. Boyd, D. A. (1957). A scrutiny of the British potato crop. *Operat. Res. Quart.* **8**, 6–21.

The paper describes an example of the application of operational research to agricultural problems, based on the Survey of Maincrop Potatoes and on summaries of experiments on aspects of potato husbandry carried out by members of the Rothamsted staff.

Except in one or two factory areas, the use of salt on sugar beet is still very limited.

190. Boyd, D. A. (1956). Weedkiller usage in England and Wales: Information from surveys of farm practice. *Rep. 3rd British Weed Control Conf.* (In the press.)

In the course of surveys of fertilizer practice, information has been obtained from a considerable number of counties in England and Wales on the use of weed-killers on farm crops. In the years 1954–56 between one-third and two-thirds of the cereal acreage in the arable districts of eastern and northern England has been sprayed annually with some form of weed-killer. Whilst the use of weed-killing sprays is most widespread in arable districts, recent surveys in Gloucestershire, Somerset and Wiltshire show that even in some typical dairying districts the practice of spraying cereals is becoming

common. In Wales and much of the south-west, however, the use of weed-killers is still exceptional, none of the surveyed areas having more than a tenth of their cereal crops sprayed. All but one-tenth of the cereal acreage in the surveyed counties in 1955–56 were sprayed with MCPA. Sowing of undersown cereals was rare in 1954, but is now becoming widespread. The use of weed-killers on peas grown for human consumption has increased rapidly, half the acreage being treated in some of the surveyed districts.

191. (Bullen, E. R.) & Lessells, W. J. (1957). The effect of nitrogen on cereals. *J. agric. Sci.* (In the press.)

Average standardized responses of the yields of wheat, barley and oats have been estimated from the results of 270 experiments carried out during the last decade in England and Wales.

With the exceptions noted below, wheat and barley crops have produced an average grain response of 3·0–3·5 cwt./acre to a standard dressing of 0·25 cwt. N/acre; this agrees well with earlier results obtained by Crowther and Yates. The widely grown winter wheat varieties, Hybrid 46, Cappelle Desprez, Bersee and Nord Desprez each produced an average response of more than 4·0 cwt./acre to the standard dressing. Of the spring barleys, Kenia, Proctor and Herta are also of greater than average responsiveness. The average response of spring oats to the standard dressing was only 1·2 cwt./acre.

The number of experiments is insufficient to allow precise conclusions to be drawn on the effect of autumn dressings, but the evidence suggests that in the drier Eastern Counties autumn nitrogen may give as good a response as the equivalent spring applications. Small dressings of nitrogen provide equal responses whether applied early or late in spring; larger applications need to be applied in early spring (March or April) to obtain the highest yields. There is no evidence that divided dressings are more responsive than a single dressing applied early in spring.

For the highly responsive varieties of winter wheat and spring barley a dressing of 0·6–0·7 cwt. N/acre is recommended, producing a net return of about £10 per acre. For other wheat and barley crops a recommended dressing of 0·5 cwt. N/acre produces a net return of about £5 per acre.

192. Church, B. M. (1956). Cereal varieties grown in England and Wales, 1952–54. *J. nat. Inst. Agric. Bot.* (In the press.)

The cereal varieties grown by farmers were recorded in the course of fertilizer surveys on random samples of farms in England and Wales during 1952–54. This note summarizes the information obtained, indicating the relative popularity of the different cereal varieties.

193. (Fisher, R. A.) & Healy, M. J. R. (1956). New tables of Behrens' test for significance. *J. R. statist. Soc. B*, **18**, 212–216.

An explicit expression for the probability integral involved in Behrens' test of significance for the difference between two means is developed for the case when both numbers of degrees of freedom are odd. This has been used to tabulate the significance points for very small samples.

194. (Foster, G.) & Rees, D. H. (1957). Upper percentage points of the generalized beta distribution. *Biometrika*. (In the press.)

The upper percentage points of the generalized beta distribution have been tabulated. These tables can be used for tests of significance in multivariate analysis.

195. Healy, M. J. R. (1957). A rotation method for computing canonical correlations. *Math. Tab., Wash.* (In the press.)

This paper describes a technique for computing simultaneously all the canonical correlations and the corresponding linear functions of the variates from a sample of $(p + q)$-variate data. The method is analogous to the Jacobi rotation method for computing latent roots and vectors of a symmetric matrix.

196. (Ashton, E. H.), Healy, M. J. R. & Lipton, S. (1957). The descriptive use of discriminant functions in physical anthropology. *Proc. roy. Soc. B.* (In the press.)

This paper describes a large-scale analysis of measurements on the teeth of humans and the great apes undertaken to clarify the relation to these groups of the recently discovered fossil anthropoids. Several measurements were taken on each tooth; the method of presentation involved the construction of a few linear functions of the measurements which provided the best discrimination between the groups. In all the teeth studied, two such functions effectively contained all the available information, and the positions of the groups could then be indicated on a plane diagram on which the fossil teeth could also be plotted. It was also possible to test whether the fossils actually lay close to the plane defined by the extant groups. In this way, the overall situation is much easier to appreciate than when the measurements are considered one at a time. The fossils studied included *Pithecanthropus pekinensis*, *Proconsul spp.* and representatives of the Australopithecinae, and the relations of these to the extant groups are discussed.

197. Leech, F. B., (Egdell, J. W. & Thomas, S. B.) (1956). A survey of methods of milk production. II. Statistical analysis of bacteriological tests on milk samples. *J. agric. Sci.* **48**, 187–193.

The results of a survey of the methods of milk production on a random sample of farms in four counties of England and Wales were used in conjunction with bacteriological and keeping-quality tests of the milk produced, to estimate the influence of factors in equipment and technique on milk quality.

Of the many factors in technique investigated, only the cooling of the milk and the sterilization of utensils appeared to affect milk quality. The effects of these two factors differed in some degree with the four tests used.

Milk samples from machine-milked herds had significantly greater thermoduric colony counts than samples from hand-milked herds. No other factor of equipment showed appreciable association with milk-quality tests.

Brief recommendations are made about the conduct of any future field survey of factors affecting bacteriological and keeping quality of milk.

198. Lipton, S. (1957). Some statistical applications of electronic computers. *Appl. Statist.* (In the press.)

The paper describes in general terms some of the work that has been carried out by the Statistics Department at Rothamsted Experimental Station, using an electronic computer.

199. Lipton, S. (1957). Two programming techniques for one-plus-one address computers. *J. Ass. Comput. Machinery.* (In the press.)

A general description is given of a routine for printing programmes in logical order. The routine provides a powerful method of detecting certain types of error in the examined programme. The paper also describes the use of a special form of link order for which only some of the digits have their normal connotations, the remainder specify parameters.

Both techniques are suitable for one-plus-one address computers.

200. (Paterson, A. B., Stuart, P.) & Leech, F. B. (1957). The use of tests on slaughterhouse cattle for estimating relative potencies of tuberculins and for the calculation of discrimination tests. *J. Hyg., Camb.* (In the press.)

The potency of PPD tuberculin made from AN5, a bovine strain, was high when WR medium was used and low when BAI medium was used. PPD tuberculin made from strains of the human type grown on BAI medium was intermediate in potency between the two bovine PPDs.

The standard deviation of the difference between responses to duplicate injections of human type PPD at 2·0 mg./ml. concentration was $\pm 2{\cdot}59$ in the Islington and $\pm 1{\cdot}84$ in the Weybridge experiment on tuberculous animals, and $\pm 1{\cdot}11$ at Islington and $\pm 1{\cdot}13$ at Weybridge on tubercule-free animals.

Differences greater than 1·5 mm. were relatively infrequent on tubercule-free animals.

The Elliott 401 electronic computer at Rothamsted was used to calculate discriminant functions and to estimate the discriminating power of different "tests", each test involving an injection of a mammalian and an injection of avian tuberculin.

There were some differences between the mammalian preparations in their power to discriminate between tuberculous and tubercule-free animals, but these differences were closely allied to differences in potency. It seems probable that if concentrations of equivalent potency were used there would be little if any difference in their discriminating power.

The contribution of avian tuberculin to the discrimination test was demonstrated; the greatest contribution came from a concentration of 0·25 mg./ml. used in the Islington experiment. The Weybridge results were quite consistent with the assumption that a maximum contribution is made by a concentration less than 0·5 mg./ml.

Methods for deducing rules for the interpretation of comparative tuberculin tests (using a mammalian and an avian tuberculin) are demonstrated and results given for the type of population sampled in these experiments. The principle on which this rule might be modified where the population is believed to be free of infection is outlined and discussed.

201. Patterson, H. D. (1957). The analysis of a non-replicated experiment involving a single four-course rotation of crops. *Biometrics*. (In the press.)

This paper considers the estimation of the errors of an unreplicated four-course rotation experiment on the residual effects of various organic and phosphatic treatments. Separate estimates of plot error and plots × years error are obtained from the year-to-year variances of selected contrasts known to be small in magnitude. As a result of the lack of replication plot totals are not orthogonal with certain treatment comparisons which cannot be ignored. This difficulty is resolved by replacing the plot totals by quantities exhibiting the required property of orthogonality. The separation of blocks × years in the analysis of variance is shown to be unnecessary in this particular experiment.

202. (Rhys, I. W., Culpin, S., Forsyth, G. E.) & Westmacott, M. H. (1957). Diets for laying fowls. An experiment testing the use of home-grown grains, and comparing protein from animal and vegetable sources as supplements to ground whole cereals. *Exp. Husb.* no. 2, 50–68.

The results of an experiment lasting three years at Gleadthorpe Experimental Husbandry Farm are presented and discussed. Four diets were compared in four different systems of housing, using a total of 7,371 hens. A diet consisting mainly of home-grown grains was as satisfactory for egg production as one containing 25 per cent of imported maize and wheat offals. A diet containing no animal protein gives 15 per cent fewer eggs in the year than a diet containing 10 per cent of fish meal, when the birds were housed in batteries. There was no difference, however, when the birds were housed in colony houses or in folds. A diet containing only 2 per cent of fish meal was slightly inferior to that containing 10 per cent of fish meal in the batteries, and was quite adequate under other conditions.

203. (Schofield, R. K.) & Rees, D. H. (1956). Calculation of membrane pressure for a sol of spherical particles. *J. Colloid. Sci.* **11**, 617–622.

For summary see no. 34.

204. Westmacott, M. H. & (Whitwell, A. W.) (1957). Some experiments on the feeding of procaine penicillin to pigs. *Exp. Husb.* no. 2, 43–49.

Five trials on the feeding of penicillin to pigs are reported, and the results are compared with those of a series of experiments carried out under the aegis of the Agricultural Research Council in 1951–52. Taking the results of the

two sets of trials together, the gain in rate of growth from feeding penicillin in the fattening period, to pigs which have not had it in the creep, was about 8 per cent, and the saving in food consumption per lb. weight gain about 5 per cent. There appeared to be very little effect from feeding penicillin in the creep to normal litters.

205. Yates, F., Healy, M. J. R. & Lipton, S. (1957). Routine analysis of replicated experiments on an electronic computer. *J. R. statist. Soc. B.* (In the press.)

Since the installation of the electronic computer at Rothamsted, programmes have been written for analysing the common types of experimental design, and a large number of analyses are now carried out annually. The paper describes the methods used in the analyses and the organization of the input of data and of the presentation of the results.

206. Yates, F. & Lipton, S. (1957). An automatic programming routine for the Elliott 401. *J. Ass. Comput. Machinery.* (In the press.)

The paper gives a brief description of an automatic programming routine developed for the Elliott 401 computer. This routine permits the orders to be written in a simplified code without specification of the address of the next order. These orders are then recoded by the machine in such a manner that all the standard conditions required by the programming rules are satisfied and the timing is reasonably optimal. At the same time any definite or probable errors which can be detected from internal evidence are indicated.

Tables

207. (Fisher, R. A.) & Yates, F. (1957). *Statistical tables for biological, agricultural and medical research.* 5th Edition. Edinburgh : Oliver & Boyd.

Review

208. Healy, M. J. R. (1956). "Principles and practice of field experimentation", by J. Wishart and H. G. Sanders. 2nd Edition. *J. R. statist. Soc. A,* **119**, 89.

Reports

209. Dunwoody, J. H. A. & (Thomson, D. C. G.) (1956). Report on plant distribution yield trials 1954 and 1955. British Sugar Corporation Ltd. *Comm. Pap. Sugar Beet Res. Comm.*, 411.

210. Leech, F. B. (1956). The testing of drugs intended for use against trypanosomiasis. Colonial Office duplicated report, TFTC(CP)(O)(56)2.

211. Simpson, H. R. (1957). The effect of sterilized males on a natural tsetse fly population. Report to Colonial Office.

Soil Survey of England and Wales

212. Avery, B. W. (1956). A classification of British soils. *Rep. 6th int. Congr. Soil Sci.* **E**, 279–285.

Following a primary division into automorphic and hydromorphic soils, 10 major soil groups are distinguished, primarily by water relationships and humus form and further divided into 39 sub-groups with specific profile characteristics. It is suggested that soil mapping units, including soil series, might be considered primarily as geographic concepts and not directly related to taxonomic soil groups.

213. Osmond, D. A. (1956). *Report on some Cyprus soils.* London : Colonial Office. Pp. 81.

An account of a visit to Cyprus to initiate a soil survey. Profile descriptions are given of the soils seen and a provisional classification drawn up.

214. Osmond, D. A. (1956). Recent advances in pedology. *Sci. Progr.* **44**, 682–687.

215. Seale, R. S. (1956). The heavy minerals of some soils from the neighbourhood of Cambridge, England. *J. Soil Sci.* **7**, 307–318.

The presence of characteristic heavy minerals assists in differentiating between glacial drifts that are the parent materials of the soils.

General Publications

216. Boalch, D. H. (1956). Rothamsted Experimental Station. *Library resources in the Greater London area,* 5 (Agricultural libraries), 7–10.

Publications of the Rothamsted Experimental Station

(*obtainable from the Librarian*)

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Catalogue of the printed books on agriculture published between 1471 and 1840, by Mary S. Aslin. (Rothamsted, 1926.)*
—*Second Edition.* (Rothamsted, 1940. Cloth, 15/-; paper 12/-.)
—*Supplement* . . . List of additions since 1940. (Rothamsted, 1949; paper, 2/6.)
Catalogue of serial publications in the Library, 1953. Edited by D. H. Boalch. (Rothamsted, 1954; 17/6.)
Catalogue of serial publications in the West Building Library at Rothamsted (Entomology, Insecticides, Mycology), March, 1956. Edited by D. H. Boalch. (Rothamsted, 1956; mimeographed; 2/-.)
The Manor of Rothamsted: [a history and guide], by D. H. Boalch. (Rothamsted, 1953; 7/6.)

PRINTS AND DRAWINGS

Mezzotint engravings by Julia Clutterbuck, A.R.A., after portraits of the founders of Rothamsted Station, Sir John Lawes (by H. Herkomer) and Sir J. H. Gilbert (by F. O. Salisbury):

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Plans and drawings of the old Rothamsted Laboratory, [?1855];

Four lithographs after drawings by Sir Charles Lawes-Witte-wronge, son of Sir John Lawes, in a volume 21½ in. by 14½ in., £1.

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* Out of Print.

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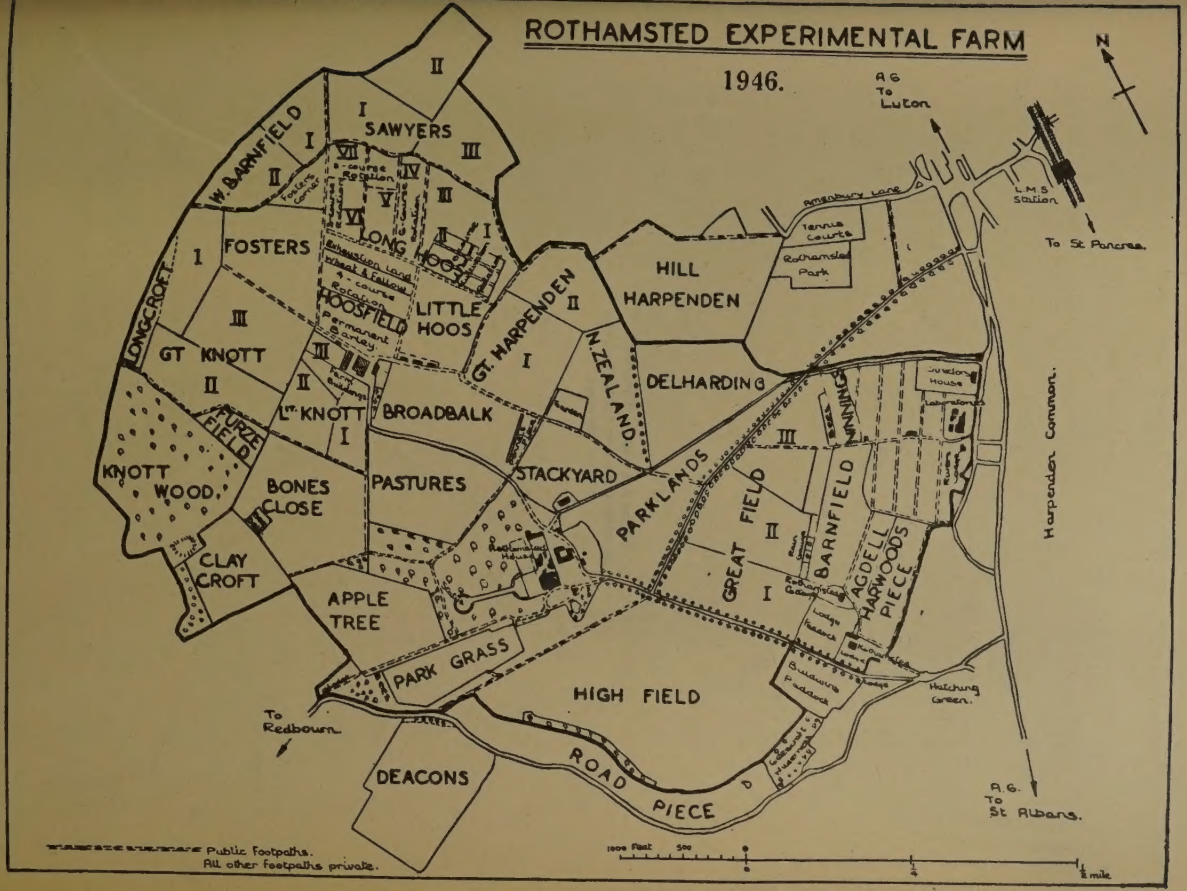
ROTHAMSTED EXPERIMENTAL FARM
1946.
N
A6 To Luton
L.M.S. Station
To St Pancras.
Amphitheatre Lane
Tennis Courts
Rothamsted Park
HILL HARPENDEN
DELHARDING
N. ZEALAND
GT. HARPENDEN
LITTLE HOOS
LONG HOOS
HOOSFIELD
SAWYERS
W. BARNFIELD
FOSTERS
LONGCROFT
GT KNOTT
LTE KNOTT
BROADBALK
PURZE FIELD
KNOTT WOOD
BONES CLOSE
PASTURES
STACKYARD
PARKLANDS
GREAT FIELD
BARNFIELD
AGDELL
HARWOODS PIECE
CLAY CROFT
APPLE TREE
PARK GRASS
HIGH FIELD
ROAD PIECE
DEACONS
To Redbourn.
Victoria House
Harpenden Common.
Hatching Green.
A.G. To St Albans.
Public Footpaths.
All other footpaths private.
1000 Feet 500
¼ ½ 1 mile

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